Increment II

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Application
ARCO/SOHIO PRUDHOE BAY - INCREMENT II

DCN 79-120-052-03

PSD PERMIT APPLICATION FOR THE PRUDHOE BAY UNIT PRODUCED WATER INJECTION, LOW PRESSURE SEPARATION, AND ARTIFICIAL LIFT PROJECTS

INCREMENT II

Submitted by:

SOHIO PETROLEUM COMPANY AND
ARCO OIL AND GAS COMPANY
ON BEHALF OF THE PRUDHOE BAY
UNIT OWNERS

Submitted to:

U. S. Environmental Protection Agency
Region X
and the
State of Alaska Department of Environmental Conservation

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28 September 1979

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1.0 EXECUTIVE SUMMARY

Purpose of This Document

This document is in support of applications for permits to construct expansion facilities at the Prudhoe Bay Oil Field, Alaska in accordance with the requirements of the Environmental Protection Agency's (EPA) Prevention of Significant Deterioration (PSD) regulations, promulgated June 19, 1978.* This document is presented by Sohio Petroleum Company (SOHIO) and ARCO Oil and Gas Company (a division of Atlantic Richfield Company) (ARCO), on behalf of the Prudhoe Bay Unit Owners.

Background

Oil production from the Prudhoe Bay Oil Pool began in 1977. During the past two years continued field development including facility expansions have brought the current production to approximately 1.2 million barrels of oil per day. Approval for the latest facility expansion was granted by EPA Region X in May 1979 for the installation of several new gas-fired turbines. The Unit owners have determined that further facility expansion is required to increase oil recovery and field oil offtake rates. These expansions include facilities for Produced Water Injection (PWI), Artificial Lift (AL), Low Pressure Separation (LPS) and Waterflood (WF). New facilities for PWI, AL, LPS and ancilliary equipment are covered in this document. The new Waterflood facilities are covered under a separate PSD application.

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*Operators are aware, as a result of Court decisions, that change to the present PSD regulations have been proposed.

Project Description

The new PWI, AL, and LPS projects represent the application of proven technologies to increase oil recovery and to maintain crude oil production from the Prudhoe Bay reservoir. Produced Water Injection (PWI) involves separating and injecting water produced with the oil back into the ground. Artificial Lift (AL) involves artificially "lifting" the crude oil up the well with natural gas. The Low Pressure Separation (LPS) project is required to reduce the wellhead pressure in the surface separation process as reservoir pressure declines.

Project Schedule

Procurement will be initiated in early 1980 and will not be completed until the end of 1984. Module fabrication will begin in mid-1980 and will continue through the end of 1984. Installation will begin in mid-1981 and continue through the latter part of 1985. Start up of the PWI, AL and LPS projects will be continuous over approximately 3½ years starting in 1982 and ending in 1985.

Air Pollutant Emissions Sources

Atmospheric emissions from the new PWI, AL and LPS facilities will be produced by about thirty-one (31) gas-fired heaters totaling 1,520 million Btu/hr and approximately 42 gas-fired combustion turbines totaling 827,000 horsepower. These sources will have total potential emissions as shown below.

Pollutant	Potential Emissions Tons/Yr
NO_x	22,645
HC (total)	744
CO	4,099
TSP	586
SO_2	18

PSD Applicability

The new PWI, AL and LPS facilities are subject to PSD review because they have the potential to emit NO_x, CO, and TSP in excess of 250 tons/yr. Although total hydrocarbon emissions may exceed 250 tons per year (based on estimates made using EPA emission factors), non-methane hydrocarbon (NMHC) emissions will be less than 250 tons per year.

Because of the low NMHC emissions and the lack of evidence for significant photochemical formation of ozone in the Prudhoe Bay area, an analysis of the impact of NMHC emissions on ozone levels was not performed. Rather, the impacts of total hydrocarbon emissions on the federal 3-hour (6-9 a.m.) NMHC guideline of 160 $\mu g/m^3$ were predicted and shown to be low (9.6 $\mu g/m^3$ as compared to an estimated background of 40 $\mu g/m^3$).

Control Technology Review

All applicable state and federal emission regulations will be met.

The proposed sources will emit more than 50 tons/yr of NO_x, HC, CO and TSP and therefore, Best Available Control Technology (BACT), must be applied to these emissions.

--For Combustion Turbines--

NO_x - BACT is natural gas-firing. Dry controls of NO_x were determined to be commercially unavailable within the time frame defined for the desired application. Water or steam injection are neither technically plausible, environmentally acceptable, nor economically feasible for use on the North

Slope. Firing with oil would yield more emissions of all pollutants than gas-firing.

TSP - BACT is natural gas-firing. There is no alternative which produces lower TSP emissions.

HC, CO - BACT is "no control". Reducing HC and CO emissions would increase NO_x emissions. This would be counterproductive to overall emission control.

--For Process Heaters--

NO_x - BACT is natural gas-firing. High efficiency NO_x removal systems such as off-stoichiometric combustion are still in the unproven stage and should not be experimented with in the harsh Arctic environment. More commonly used NO_x controls such as controlled combustion have the potential for maintenance and safety problems because of the environment. Also, most of the heaters are too small to make control investments economical when compared with benefits.

HC, CO, TSP - BACT is natural gas-firing. No alternative controls are available to achieve lower emissions than natural gas-firing.

Air Quality Review

The Prudhoe Bay area is an attainment PSD Class II area for all criteria pollutants. The results of the air quality impact analyses show that none of the National Ambient Air

Quality Standards (NAAQS) or applicable PSD increments are exceeded as a result of emissions from the new PWI, AL, and LPS facilities. Baseline air quality concentrations were calculated by adding dispersion model predictions for <u>baseline</u> (non-PSD) sources, both Unit and non-Unit, to background levels estimated from ambient measurements. PSD (increment consuming) sources modeled include 1) all sources permitted in the Unit's 1978 PSD application (approved May 1979), and 2) all proposed sources for PWI, AL, and LPS.

The pollutant of primary concern for this application is NO_2 for which there is an annual NAAQS limit of 100 $\mu g/m^3$. Dispersion modeling results show that the highest predicted NO_2 concentration from all sources, including existing sources and background, is 69 $\mu g/m^3$. The contribution of the PWI, AL and LPS sources to this maximum is about 1 $\mu g/m^3$. The highest annual NO_2 contribution predicted for the proposed PWI, AL and LPS sources is 6 $\mu g/m^3$ at a point where the total impact of all sources is 13 $\mu g/m^3$.

Stack heights will not exceed Good Engineering Practice (GEP) heights. The potential impact from downwash from heater stacks was analyzed and was shown to be insignificant.

Existing Air Quality

The Unit is currently conducting a one-year ambient air monitoring program at two sites on the North Slope for NO_2, TSP, ozone, CO, HC, SO_2 and meteorology. Descriptions of the equipment, operations and quality assurance procedures have already been provided to EPA Region X and the State of Alaska Department of Environmental Conservation (DEC). The first quarterly data report (March-June 1979) submitted separately, shows that all pollutant levels are low, well within NAAQS. Measured NO_2 levels, for example, are less than 5 percent of the standard.

Maximum 1-hour ozone levels measured at the Unit stations peaked in April at levels less than half the standard. Seasonal variation is expected to be small. Five years of research by NOAA at Point Barrow suggest that the monitors have either already measured the peak ambient ozone concentrations for the year or have measured levels close to the peak.

Impacts on Visibility, Soils and Vegetation

The impact on visibility, soils and vegetation in the Prudhoe Bay area resulting from emissions of the new facilities will be negligible.

Impacts of Construction and Growth

The impact of construction of the new facilities on air quality will be small largely due to the fact that all equipment will probably be fabricated at existing sites in the contiguous United States. Reasonable precautions at Prudhoe Bay will be taken to minimize fugitive dust emissions during site construction in accordance with state criteria.

There will be little secondary growth accompanying the operation of the new facilities.

2.0 INTRODUCTION

2.1 Applicant Information

This application is a dual application by SOHIO Petroleum Company (SOHIO) and ARCO Oil and Gas Company (a division of Atlantic Richfield Company) (ARCO), operators on behalf of the Prudhoe Bay Unit. Addresses and contacts are as follows:

Owners

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Location of Source

Prudhoe Bay Unit
Prudhoe Bay, Alaska
Approximate Center of Prudhoe Bay Unit:

Latitude:	70° 17' N
Longitude:	148° 34' W
UTM Coordinates:	440.7 East
	7797.2 North

2.2 Source Information

The Prudhoe Bay Unit Operators propose to construct additional facilities at the Prudhoe Bay Oil Field on Alaska's north slope to maintain oil extraction rates as well as to allow for continued expansion of the field. The location of the Prudhoe Bay area is shown in Figure 2-1. These facilities will serve to:

(1) reduce surface separation pressure which is termed Low Pressure Separation (LPS),

(2) artificially gas lift the crude oil up the well with natural gas, termed Artificial Lift (AL),

(3) provide for the disposal of produced water by subsurface injection, termed Produced Water Injection (PWI), and

(4) allow well production testing at the well pads.

The facilities required consist of turbine driven pumps, gas/crude oil/produced water separators, heaters, gas treating, produced water treating, and pipelines. In addition, three fuel oil storage tanks and three ullage tanks for emergency use only will be constructed. Additional emergency flaring capacity will be required. A schematic of the proposed systems is shown in Figure 2-2.

Atmospheric emissions will be produced by turbines and heaters at the gathering centers, flow stations, and the Central Compressor Plant, and by additional heaters at the well pads

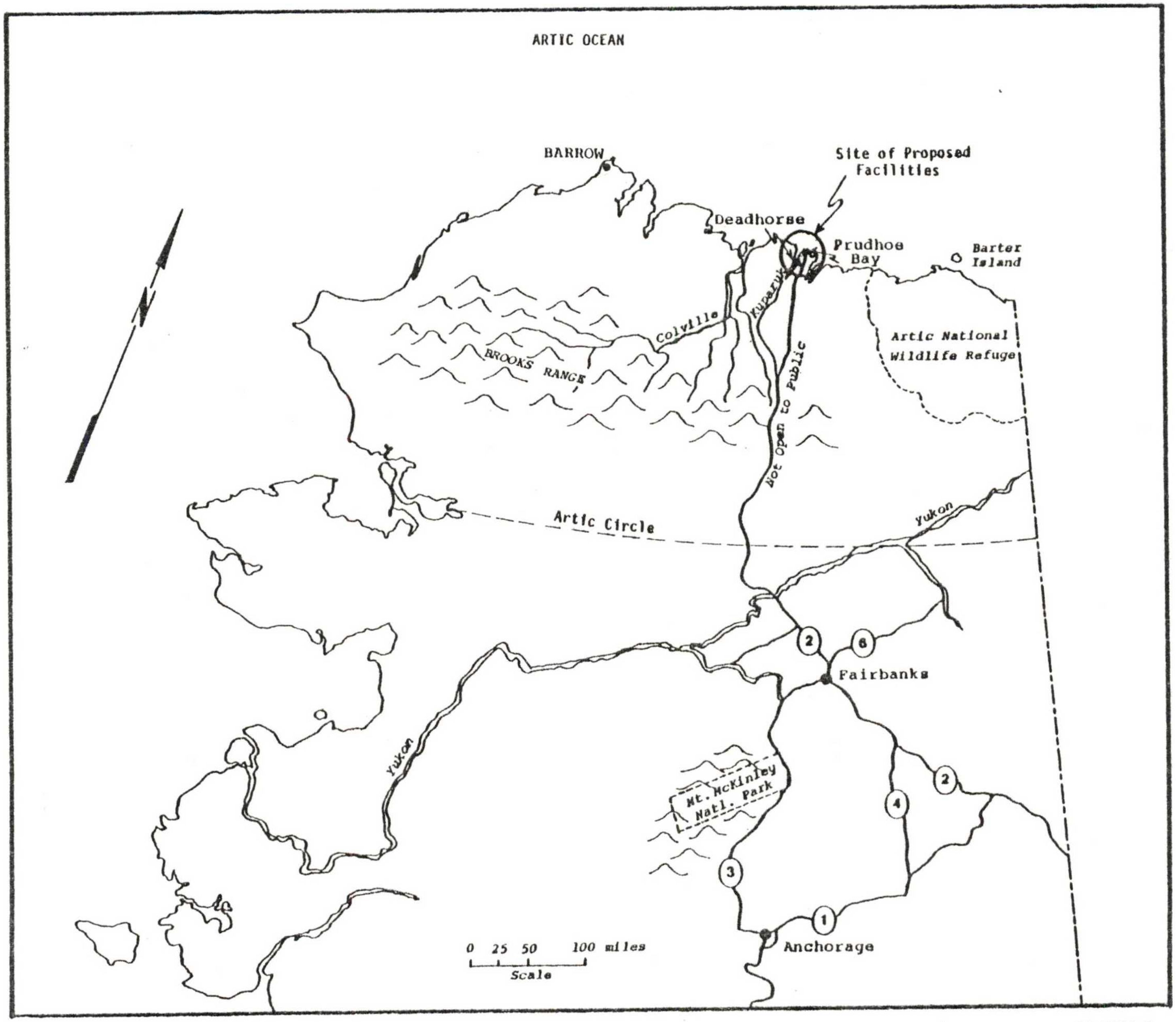

Figure 2-1. Location of Prudhoe Bay Area

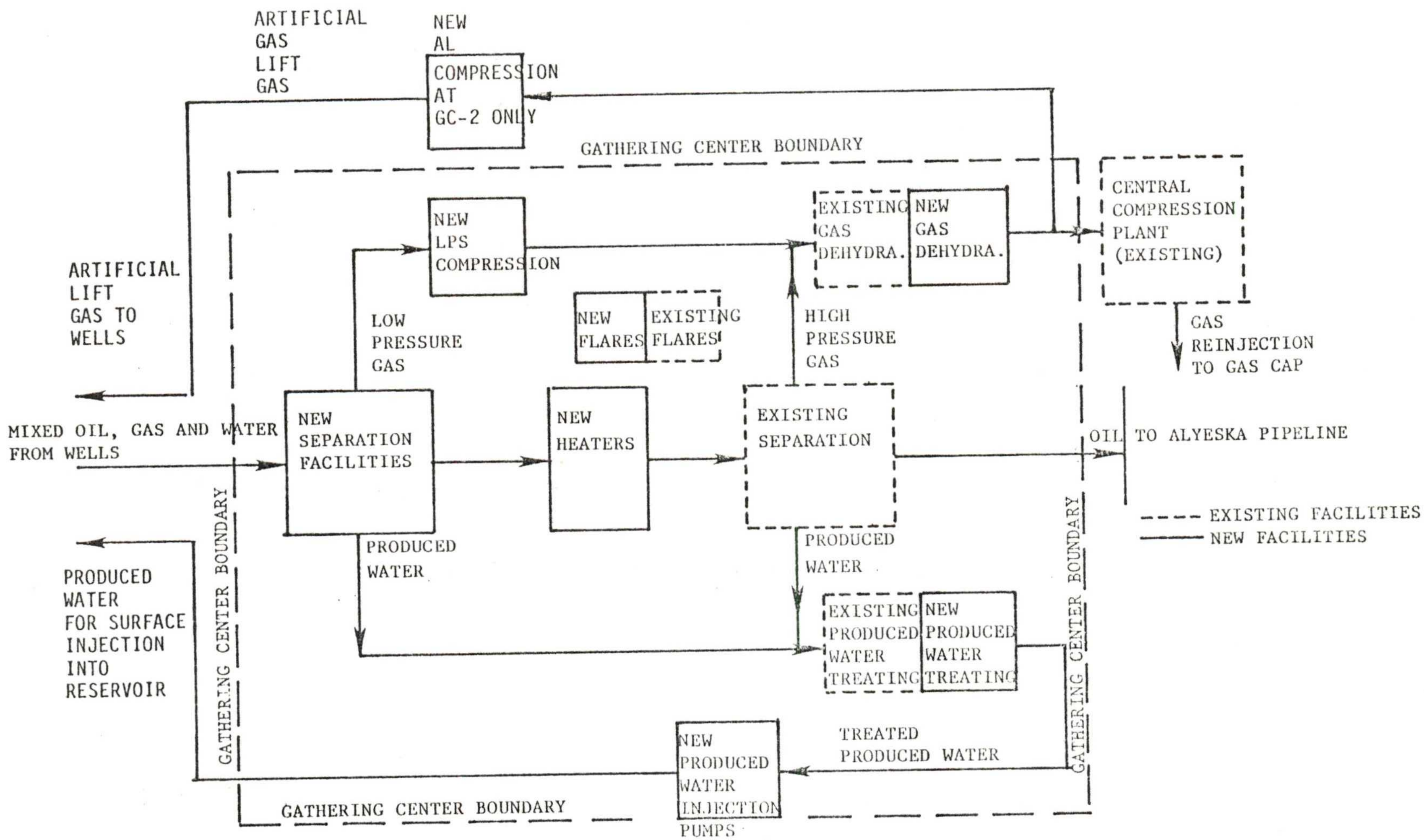

FIGURE 2-2

PROPOSED SYSTEM SCHEMATIC OF PRODUCED
WATER INJECTION, LOW PRESSURE SEPARATION
AND ARTIFICIAL LIFT PROJECTS

operated on SOHIO's portion of the Prudhoe Bay Unit. The heaters, having an approximate total heat input of 1,530 x 10^6 Btu (1,520 mm Btu) per hour; and the turbines, operating at an approximate total combined rating of 827 x 10^3 horsepower (827 MHP), will be fired by natural gas.

In accordance with Section 165 of the Clean Air Act, the Prudhoe Bay Unit Operators are applying to EPA Region X for a permit which will certify that the new facilities will be consistent with the Act's rules for Prevention of Significant Deterioration (PSD) of air quality and that they will implement Best Available Control Technology (BACT). This document is intended to support the granting of such a permit.

3.0 DESCRIPTION OF THE PROPOSED EMITTING FACILITIES

Four types of facilities to be installed will generate or will have the potential to generate pollutants. These are:

(1) Combustion Turbine Prime Movers
(2) Process Heaters
(3) Petroleum Storage Tanks, and
(4) Gas/oil/water separator vessels.

Emissions from the first three will be vented directly to the atmosphere, although the quantities from the third source, the tankage, will be negligible. Under normal circumstances, there will be no emissions from the gas/oil/water separators, since return of gas and water to the subsurface producing formation is an integral part of the present design. (Upon the development of gas sales, gas injection will of course largely cease). However, in an emergency and to protect lives and the installations, some gas may be flared to the atmosphere for minimal periods. The total horsepower and heater duty as well as the specific turbine and heater sizes at each gathering center, flow station, well pad, and at the Control Compressor Plant represent current engineering design requirements. The locations of these facilities and associated emissions sources are illustrated in Figure 3-1. Table 3-1 lists the new emissions sources associated with the project.

The Turbines

There are anticipated to be 42 compressor-drive combustion-turbines installed at Prudhoe Bay. These will be fired with natural gas from the Prudhoe Bay Field. They will vary in approximate individual power ratings from 1,400 horsepower to 36,000 horsepower for a combined total of 827,000

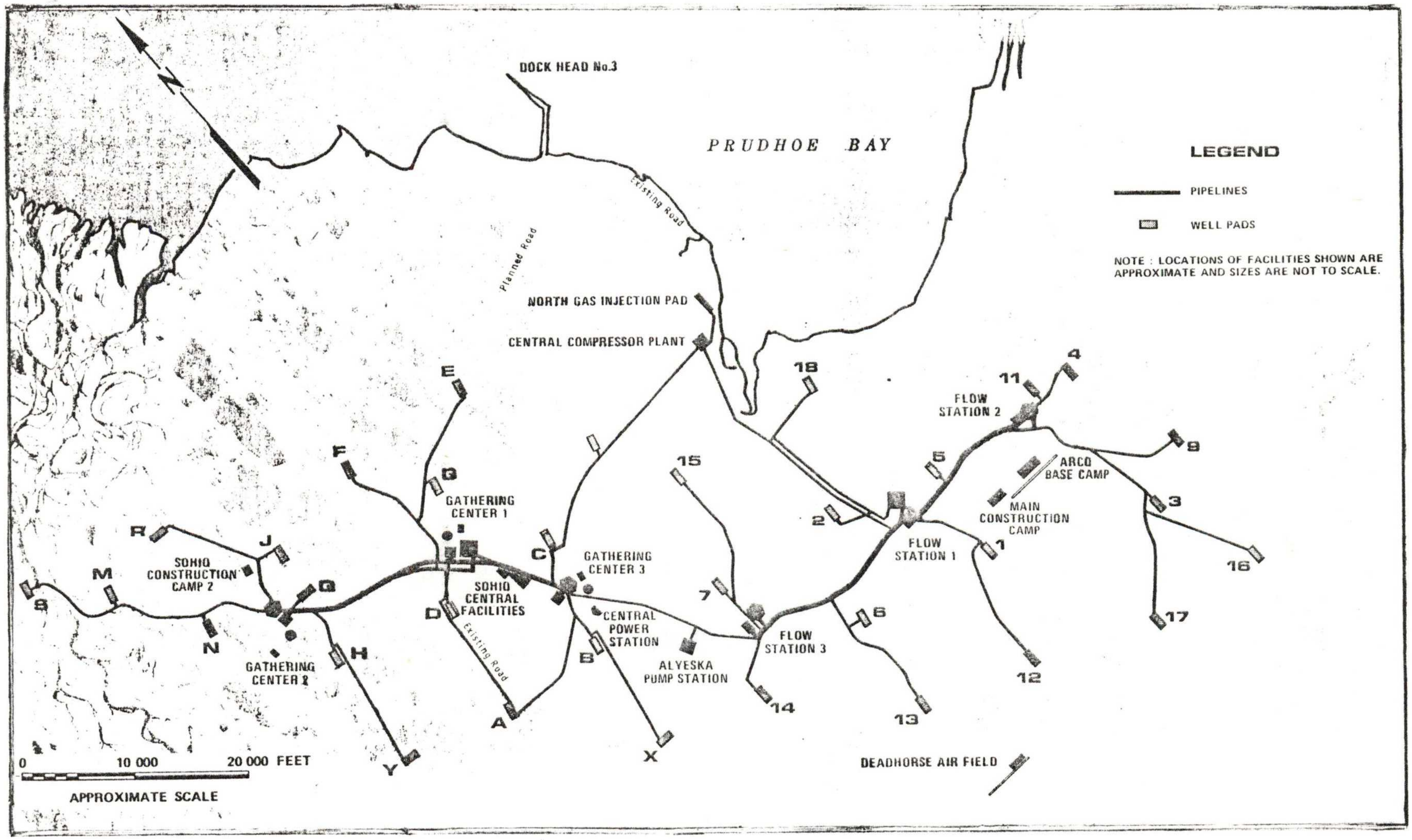

Figure 3-1. Layout of Project Facilities

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TABLE 3-1

LIST OF ANTICIPATED NEW EMISSIONS SOURCES

Location	Equipment	Rating	Quantity
SOHIO Gathering Center 1	Combustion Turbines	3.5 MHP	2
		1.4 MHP	1
		22.6 MHP	4
	Gas Heaters	42.5 mm Btu/hr	2
		5.0 mm Btu/hr	1
		310.5 mm Btu/hr	1
SOHIO Gathering Center 2	Combustion Turbines	3.5 MHP	2
		1.4 MHP	1
		22.6 MHP	4
		26.6 MHP	3
	Gas Heaters	42.5 mm Btu/hr	3
		310.5 mm Btu/hr	1
		5.0 mm Btu/hr	1
SOHIO Gathering Center 3	Combustion Turbines	3.5 MHP	2
		1.4 MHP	1
		22.6 MHP	4
	Gas Heaters	42.5 mm Btu/hr	2
		5.0 mm Btu/hr	1
		310.5 mm Btu/hr	1
SOHIO Well Pads A, B, C, D, E, F, G, H, J, M, N, Q, R, S, X, Y.	Gas Heaters	10.0 mm Btu/hr	16 (1 per pad)
Central Compressor Plant	Combustion Turbine	25.0 MHP	1
	Gas Heater	26.0 mm Btu/hr*	1
ARCO Flow Station 1	Combustion Turbines	5.0 MHP	2
		36.0 MHP	3
ARCO Flow Station 2	Combustion Turbines	36.0 MHP	4
		5.0 MHP**	2
	Gas Heater	100.0 mm Btu/hr	1
ARCO Flow Station 3	Combustion Turbines	36.0 MHP	4
		5.0 MHP**	2
SOHIO Gathering Centers	Fuel Oil Storage Tanks	42,000 gallons	3 (1 per center)

* Previously permitted by State in June 1979.
**One of these units was previously permitted by the State in June 1979.

horsepower. Because of extremely high combustion temperatures, oxides of nitrogen (NO_x) are the emissions of greatest quantity from the turbines, but the other pollutants will also be emitted. Emissions and stack parameters are presented in Appendix C.

The turbines will be housed in buildings of yet to be determined dimensions, but approximately 60 feet in height. Ducts will carry the exhaust gases through the sides of the buildings and into stacks mounted to the sides of the buildings. The stacks will extend to approximately 60 feet above ground level.

These turbines will be located at SOHIO's gathering centers, ARCO's flow stations, and the ARCO Central Compressor Plant. The distribution of turbines among gathering centers and flow stations will be roughly equal both in terms of number and total capacity, about six to ten apiece representing between 99,000 and 154,000 horsepower. The Central Compressor Plant will have one 25,000 horsepower turbine. These sites are located on Figure 3-1.

Combustion turbines operate by drawing air through an intake, then compressing the air with the front-end turbine blades, and forcing the air into a combustion chamber. A very hot flame fueled by gas or oil (gas for this application) causes continuous rapid heating and thus expansion of air within the combustion chamber. This expansion of air imparts a force on the remaining sets of turbine blades, causing them to move and the shaft to rotate. The exhaust air proceeds out the stack as a combination of air, combustion products (CO_2 and H_2O), and products of endothemic reactions such as NO and CO. The gases exit at high velocity and temperature. A typical turbine is sketched in Figure 3-2.

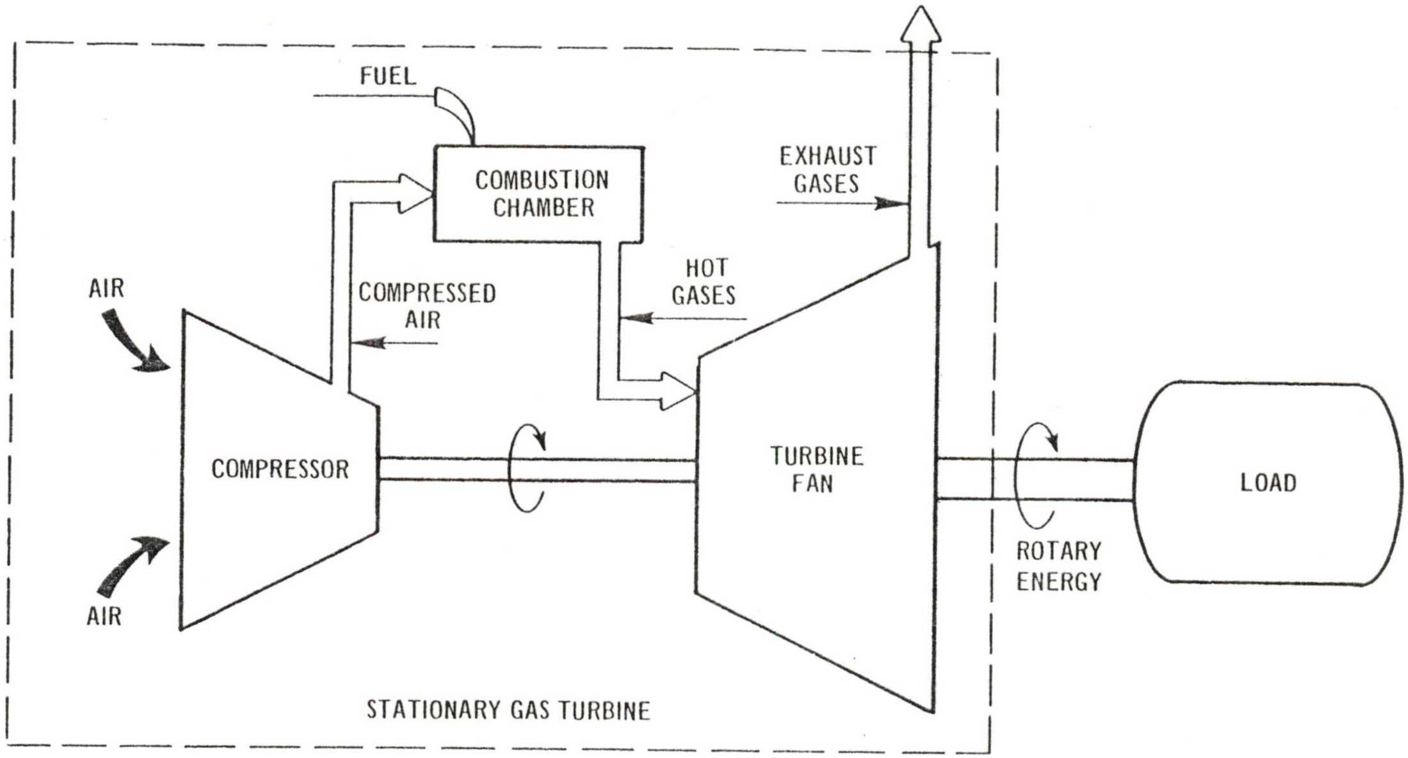


Figure 3-2. Typical simple cycle gas turbine.

The Process Heaters

About thirty-one process-heaters will be installed at Prudhoe Bay. These will be fired with natural gas from the Prudhoe Bay Field. They will vary in individual heat output capacity from about 5 mm Btu per hour to about 310.5 mm Btu per hour. Oxides of nitrogen (NO_x) are the largest pollutant emissions from the heaters also. Other pollutants will be emitted in small amounts. Emissions from the heaters are presented in Appendices B and C.

The larger heaters will be housed in buildings of dimensions not yet designated, but not exceeding 60 feet in height. Ducts will carry the exhaust gases through the sides of the buildings. The stacks will extend approximately 60 feet above ground level. As stated in the description of the turbines, the height of the buildings will not exceed 60 feet. The smaller heaters located at drill pads will typically have stacks 45 feet above the ground.

A total of fifteen heaters will be located at SOHIO's gathering centers, ARCO's Flow Station 2 and the ARCO Central Compressor Plant. One 10 mm Btu heater will be located at each of 16 SOHIO drill pads. In terms of heat capacity, the SOHIO gathering centers will be the largest heater facilities with 400.5 mm Btu capacities at GC-1 and GC-3, and 443 mm Btu at GC-2. These sites are located in Figure 3-1.

These heaters are used to heat glycol directly for subsequent heating of building air, water, oil, and miscellaneous items; to directly heat water and oil; or to regenerate TEG used in natural gas dehydrating. Emissions are generated similarly to those from the turbines, but because the flame temperature in the heaters is lower than in the turbines, the NO_x yielded per unit of fuel burned is less. There is not a rapid expansion of air in the heaters, so their exhaust gases have a low velocity in the stack.

The Petroleum Storage Tanks

Three 42,000 gallon tanks will be constructed at Prudhoe Bay for storing fuel oil. The fuel oil will be used for emergency use only. A typical tank would be approximately 25 feet in diameter and 15 feet tall. They will be of the conical fixed-roof type.

The only regulated pollutant, that will be emitted from the tanks, is hydrocarbon vapors. However, fuels of the type to be stored in the tanks are not very volatile. Furthermore, because the diurnal variation in temperature is quite small at Prudhoe Bay, breathing losses from the tanks will be small.

Some hydrocarbon emissions are forced from the tanks when they are refilled. Still, these emissions will be small, because the extreme cold and low volatility of the fuels will keep the concentration of hydrocarbons in the expelled air low.

Three 100,000 gallon ullage tanks will be constructed for the purpose of storing crude oil, if and when there is a problem in the Alyeska Pipeline or the operating equipment of the Prudhoe Bay Oil Field requiring a shutdown. Crude oil is more volatile than its fuel oil derivatives, but because the tank will only be used for emergency purposes, emissions cannot be predicted and are assumed to be nonexistent.

The Separators

The separators are pressure vessels in which gas and water are removed from freshly-produced crude oil. This process requires the addition of heat, which is supplied by the heaters. As a result, no combustion occurs in the separators themselves.

The gases will be recovered from the separators and not vented to the flares. However, for an emergency, additional flare capacity is being installed to relieve gases if a dangerous separator back pressure should build. Like those of the ullage tank, emissions from emergency flaring are unpredictable and would be very small. They are not quantified in this permit application.

Emergency Flaring Capacity

As the production of the field progresses, the gas to oil ratio will increase requiring additional gas volumes to be handled during emergencies. Additional emergency flaring capacity will therefore be installed at the three SOHIO gathering centers.

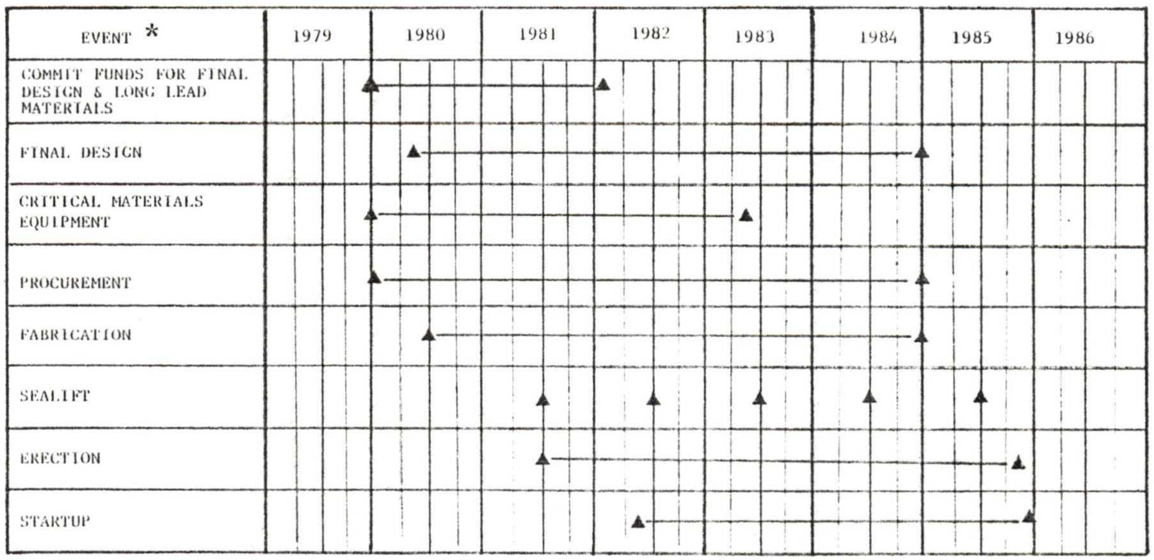
Current projections indicate that under worst-case circumstances additional flaring capacity of 500 MMSCFD would be required at Gathering Center 1, an additional capacity of 400 MSCFD at Gathering Center 2, and an additional capacity of 400 MMSCFD at Gathering Center 3. However as the plant is designed and operated to minimize frequency and duration of emergencies; and the possibilities of "worst case" emergencies are considered extremely remote, the resultant emissions will be small and are not quantified in this application.

Operating Schedule

The proposed turbines and heaters are scheduled to operate continuously all year long and should be permitted for such operation. No use of the ullage tank nor flaring of separator gases is scheduled, but infrequent operation should be permitted for emergency purposes.

Milestone Schedule

A schedule of events leading to the construction and operation of the sources to be permitted is shown in Figure 3-3.



*This schedule assumes approval of PSD permit by January 1, 1980.

Figure 3-3. Summary Milestone Schedule

4.0 DESCRIPTION OF THE EXISTING ENVIRONMENT

4.1 Site Topography and Land Use

The project area lies within the Arctic Coastal Plain of Northwestern Alaska in a region referred to as the Teshekpuk Lake section. The area is characterized by a uniformly flat terrain that slowly slopes downward to the coast of the Arctic Ocean. The elevation of the area is approximately 50 feet (15 meters) above mean sea level (see Figure 4-1). Streams, channels and other drainage systems are poorly defined and small, shallow lakes, ponds, and water-filled depressions constitute a significant portion of the surface area. A majority of the area, however, consists of a vegetated peaty bog formed on the slightly elevated areas. Permanently frozen ground underlies the entire region with the depth of the active layer (maximum depth of thaw) commonly being no more than 1.5 to 3 feet. The area is sparsely populated, and is used only for energy related activities and occasional subsistence game hunting and fishing.

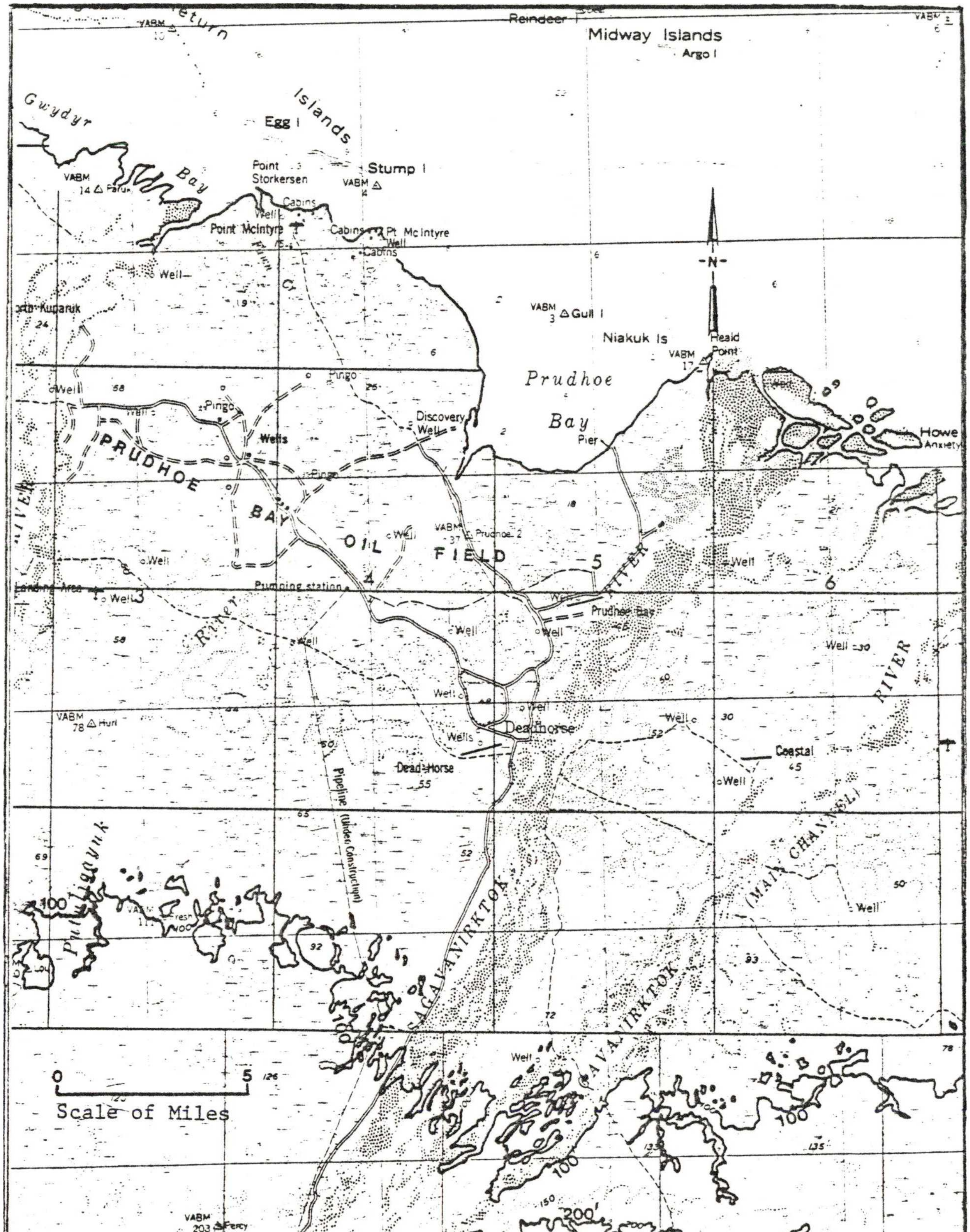


Figure 4-1. Topography of the Site Area

Note: 100-foot and 200-foot contours are highlighted.

4.2 Climate

Prudhoe Bay has a very harsh, Arctic climate with extremely cold winters and very cool summers. Precipitation during the year averages less than ten inches, but this typically includes 30 to 50 inches of snowfall. Blowing, drifting snow is common because of strong winds and the dry, powdery characteristics of most of the snow. Glaze or icing conditions are also relatively frequent during the year. Prevailing winds are from the east-northeast (off the Arctic Ocean). Annual average wind speeds are typically between ten and fifteen miles per hour. However, speeds of 30 to 50 miles per hour are common with winter storms (Ruffner, 1977).

Dispersion conditions in the project site area are generally good, primarily because of the good ventilation provided by frequent moderate to strong winds. Poor dispersion conditions do occur occasionally during stable conditions when winds are very light, but periods of poor dispersion are usually short lived.

The two nearest primary National Weather Service stations to the Prudhoe Bay area are located at Barter Island, which is approximately 120 miles east of the area, and at Point Barrow, which is approximately 200 miles west-northwest of the area. These two weather stations collect standard meteorological parameters 24 hours a day. Within the Prudhoe Bay area, the Prudhoe Bay Airport weather station (latitude 70° 15' N, longitude 140° 20' W) collects maximum/minimum temperature data. The Deadhorse Airport weather station (latitude 70° 12' N, longitude 148° 27' W) collects wind data hourly, but temperature data only sporadically.

Based on three years of data, temperatures average 7.9°F annually at the Prudhoe Bay Airport weather station. The coldest month of the year is February with a monthly average of -26°F, and July is the warmest month with a mean temperature of 45.5°F (Ruffner, 1977). In comparison, the 30-year mean annual temperatures at Point Barrow and Barter Island are 9.3°F and 10.1°F, respectively. The coldest month is February (-18.6°F at Point Barrow and -19.5°F at Barter Island) and the warmest month is July (38.7°F at Point Barrow and 40.0°F at Barter Island). The mean number of days with a maximum temperature of 70°F or above is less than one every two years at both Point Barrow and Barter Island. Conversely, the mean number of days per year with minimum temperatures of 32°F or below is 323 days at Point Barrow and 312 days at Barter Island (National Oceanic and Atmospheric Administration, 1978).

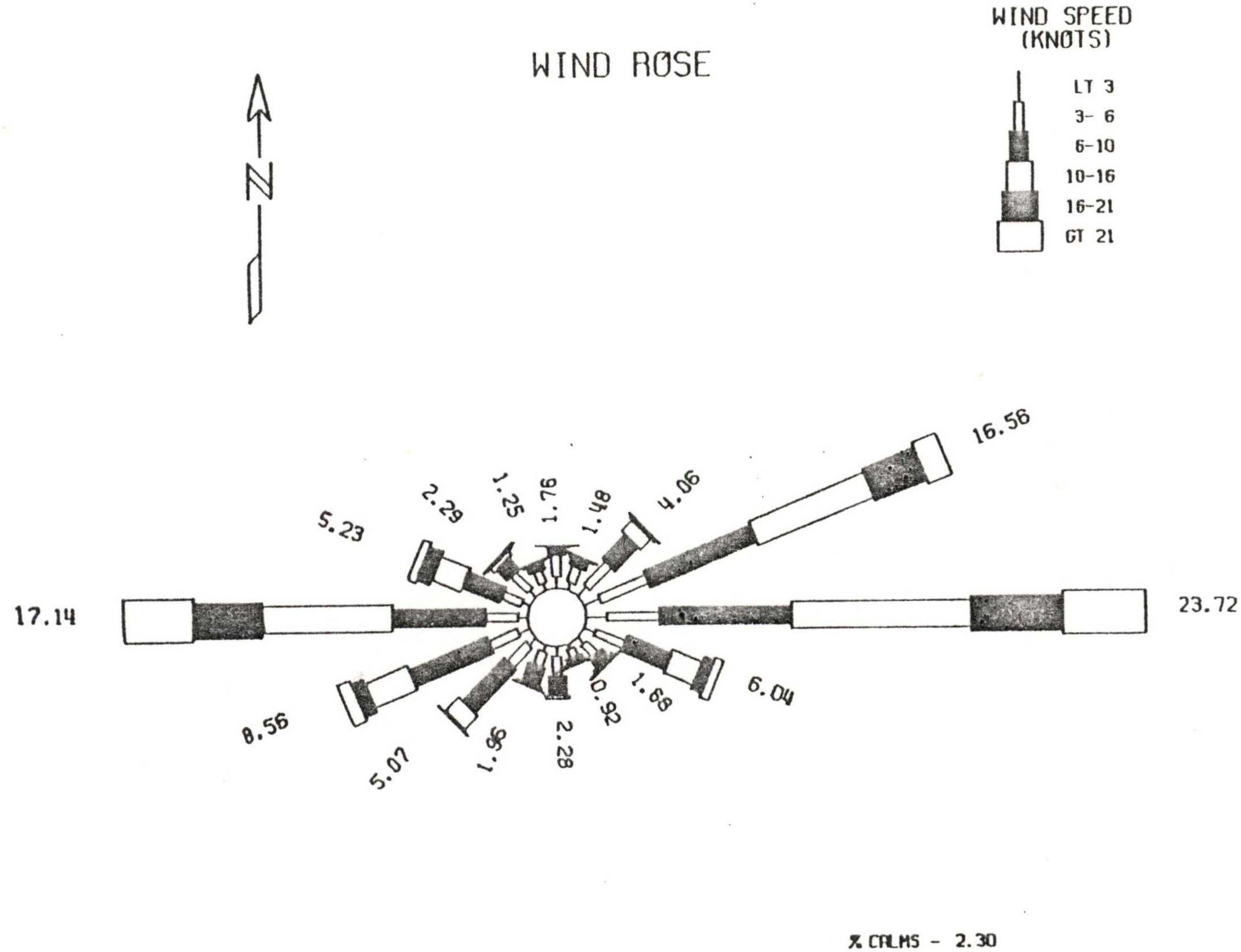
Precipitation on the North Slope consists mostly of snow and is relatively light compared to most other parts of the United States. The normal annual precipitation amounts for Point Barrow and Barter Island are 4.89 inches and 7.05 inches, respectively. The average annual snowfall at Point Barrow is 29.1 inches, while at Barter Island the annual average is a significantly greater, 47.6 inches. The month with the greatest average snowfall on the North Slope is October, with 7.2 inches at Point Barrow and 9.8 inches at Barter Island. June has the least snowfall with a 0.4-inch average at Point Barrow, while July has the least snowfall (0.4-inch average) at Barter Island (National Oceanic and Atmospheric Administration, 1978).

Ice accretion on exposed surfaces as glaze or rime can be expected on 27 days during the year. This icing frequency is the greatest in the United States, except for some mountain tops in the Northeast (Amstead, 1978).

Frequently, heavy fog develops as a result of high relative humidity and causes horizontal visibility to drop to one-quarter mile or less. Such low visibilities can be expected on 65 days annually at Point Barrow and on 75 days annually at Barter Island (National Oceanic and Atmospheric Administration 1978). At temperatures below -20°F, fog occurs in the form of ice fog. Ice fog increases in frequency with decreasing temperature and is almost always present at temperatures of -50°F and below (Huschke, 1959).

The annual wind rose (based on seven years of data) for Barter Island is presented in Figure 4-2. The annual wind rose is a frequency distribution of occurrences of each of the 16 compass-point wind directions. The wind rose indicates a bimodal frequency distribution with prevailing easterly winds. The second most frequent wind direction is west. Wind speeds average 11.5 miles per hour, with calms recorded 2.3 percent of the time (National Climatic Center, 1958-1964).

The annual wind rose (based on one year of data) for Deadhorse Airport is presented in Figure 4-3. This wind rose also indicates a bimodal frequency distribution. East-northeasterly, northeasterly, and west-southwesterly winds are most frequent, in that order. The different frequency distribution of wind direction at Deadhorse Airport compared to Barter Island may result from: (1) the short sampling period at the Deadhorse Airport versus the longer sampling period at Barter Island, (2) a large scale effect on the synoptic flow at Barter Island created by the Romanzof Mountains to the south; i.e., the mountains may divert the synoptic flow in such a way as to partially account for the differences between the Barter Island and Deadhorse Airport wind roses, and/or (3) the coastal configuration at Prudhoe Bay compared to the coastal configuration at



Source: National Climatic Center, Surface Meteorological Tape for Barter Island, Alaska--TDF 1440 DATA FORMAT. Perior of Record 1958-1964. Asheville, NC.

Figure 4-2. Annual Wind Rose for Barter Island, Alaska
Period of Record: 1958-1964

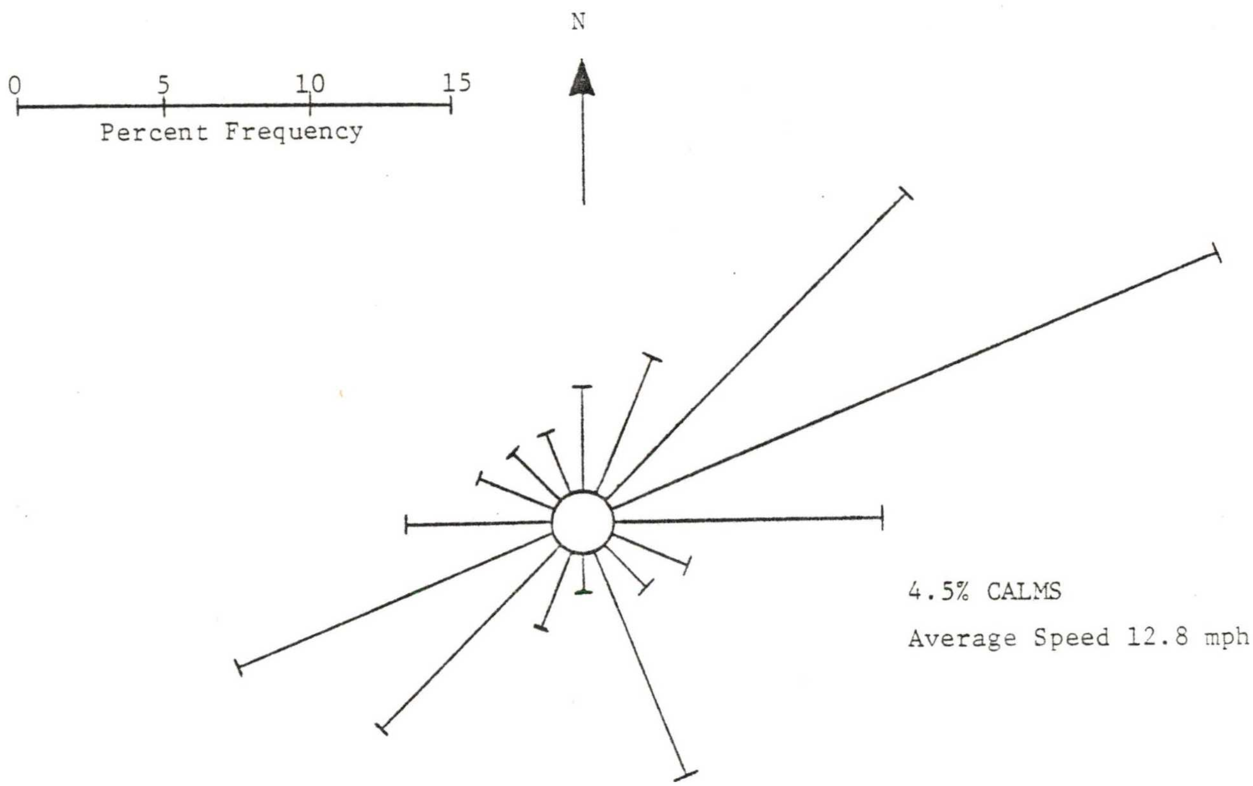


Figure 4-3. Annual Wind Rose for Deadhorse Airport, Alaska
One-year data period: 1976

Source: Dames and Moore, Prevention of Significant Deterioration Permit application submitted by Atlantic Richfield Company and Sohio Petroleum Company on behalf of the Prudhoe Bay Unit owners to the U.S. Environmental Protection Agency for construction of additional facilities at the Prudhoe Bay Oil Field, Prudhoe Bay, Alaska. Aug. 1978.

TABLE 4-1

ANNUAL FREQUENCY DISTRIBUTION OF PASQUILL STABILITY CLASSES AND WIND SPEED AT BARTER ISLAND (1958-1964)

Stability Class	Definition	Annual Frequency (percent)	Average Wind Speed (mph)
A	Extremely Unstable	0.02	Calm
B	Unstable	1.23	3.9
C	Slightly Unstable	4.98	5.7
D_1	Neutral (day)	37.47	11.7
D_2	Neutral (night)	39.94	14.4
E & F	Slightly to extremely stable	16.37	6.0

Source: National Climatic Center, Surface Meteorological Tape for Barter Island, Alaska -- TDF 1440 DATA FORMAT. Period of Record 1958-1964, Asheville, NC.

Barter Island. The mouth of Prudhoe Bay faces north and Deadhorse Airport is a few miles inland southwest of the bay. In contrast, the configuration of the coastline in the vicinity of Barter Island is east to west with no bay. The data for Deadhorse Airport indicate an average wind speed of 12.8 miles per hour, with calm conditions 4.5 percent of the time (Dames and Moore, 1978).

The annual frequency distribution of the six stability classes for Barter Island are presented in Table 4-1. Mean wind speeds associated with each stability class are also given. This table indicates that neutral stability class conditions occur about 77 percent of the time at Barter Island. According to Pasquill's standard method for determining stability classes, neutral conditions generally result from moderate to strong winds and cloudy conditions (National Climatic Center, 1958-1964). Seasonal and annual joint frequency distributions for wind speed, wind direction, and stability class, calculated from the Barter Island data, are presented in Appendix E, (National Climatic Center, 1958-1964).

4.3 Existing Air Quality

Determination of the impact of emissions from all sources (including the new facilities) in the Prudhoe Bay Unit on the National Ambient Air Quality Standards (NAAQS) requires a determination of the existing air quality of the area. This determination also illustrates the current status of compliance with the National Ambient Air Quality Standards.

Background levels, estimated from current air quality monitoring data can be added to concentrations predicted for all the sources to predict total air quality impacts. For the purposes of this document, the term "background" refers to the contributions to total air quality from all anthropogenic and natural sources outside of or upwind from the Prudhoe Bay area.

For the purposes of the PSD study, air quality data collected at two monitoring sites in the Prudhoe Bay Unit were used to characterize existing and background air quality levels. Beginning on March 16, 1979 the Unit Operators began a one-year air quality and meteorological monitoring program. The network consists of two remote sites designed to collect both air quality and meteorological parameters and a 200-foot communications tower instrumented with meteorological sensors. The remote monitors are located at Drill Site 9 and at Well Pad A and the instrumented tower is located at the SOHIO Base Operating Camp (Figure 4-4).

The following air quality and meteorological parameters are collected at each remote site:

1. Oxides of Nitrogen (NO_x)
2. Nitric Oxide (NO)
3. Nitrogen Dioxide (NO_2)
4. Sulfur Dioxide (SO_2)

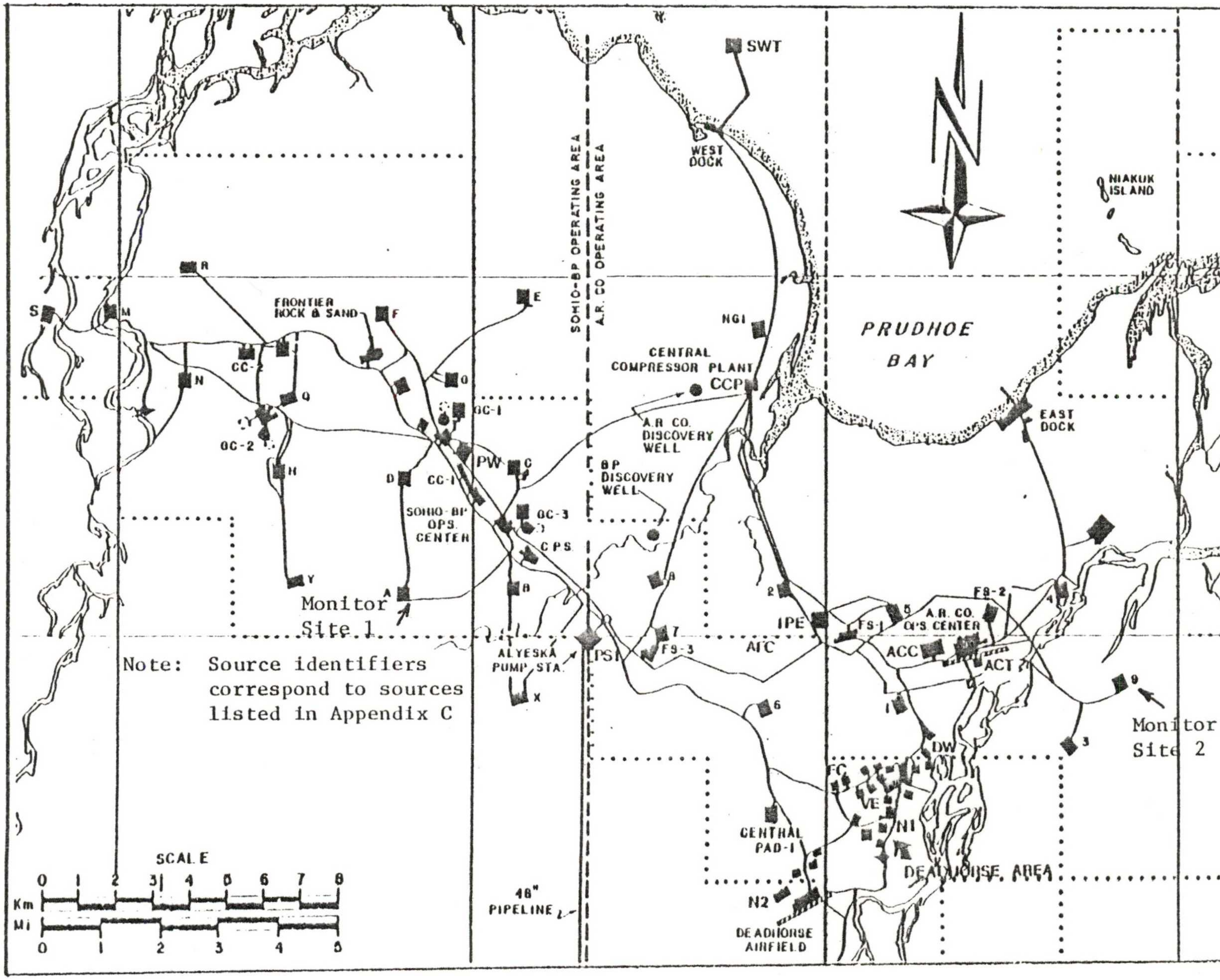


Figure 4-4. Location of Air Quality Monitors

5. Ozone (O_3)
6. Carbon Monoxide (CO)
7. Total Hydrocarbons (THC)
8. Methane (CH_4)
9. Non-Methane Hydrocarbons ($THC-CH_4$)
10. Wind Speed (33 feet)
11. Wind Direction (33 feet)
12. Temperature (33 feet)
13. Total Suspended Particulates (TSP)

In addition, precipitation and visibility are measured at Drill Site 9 (Site 2 in Figure 4-4), the upwind site, and temperature layering heights and wind profiles are measured at Well Pad A (Site 1 in Figure 4-4), the downwind site, using an ECHOSONDE® acoustic sounder system.

The following meteorological parameters are monitored at the 60 meter communications tower site:

Temperature	33-foot level
Δ Temperature	33 - 200-foot level
Wind Speed	146-foot level
Wind Direction	146-foot level
Wind Speed	200-foot level
Wind Direction	200-foot level
Wind Direction Bivane	200-foot level
1) Horizontal	
2) Vertical	

To support the monitoring activities a monitoring plan entitled Ambient Air Quality and Meteorological Monitoring Plan For Prudhoe Bay, Alaska was submitted to EPA Region X and the Alaska DEC in late 1978.

This document demonstrates that all siting, operating, quality assurance, and data validation procedures employed in the network operation correspond to guidelines established by the Environmental Protection Agency.

A quarterly report presenting hourly-averages of air quality and meteorological parameters and summary reports of the data is being submitted separate of this application. This report covers the period from March 16 until June 30, 1979.

Table 4-2 reports maximum and mean levels of NO_2, TSP, SO_2, CO, non-methane hydrocarbons (NMHC) and ozone (O_3) measured during the approximately 3½ month monitoring period. Examination of this table shows that measured levels for all pollutants are well below those concentrations allowed by the National Ambient Air Quality Standards. The results of this monitoring program as presented in this table support the current designation of the Prudhoe Bay area as in attainment of the NAAQS for criteria pollutants.

Levels of pollutants measured during the 3½ month monitoring program at the two sites in the Prudhoe Bay area should be representative of existing air quality levels in the region. Measured levels of NO_2, TSP, SO_2, CO, and HC are low at these sites, and seasonal variations in the levels of these pollutants are not expected to be significant, even if somewhat higher values are recorded during later stages of the monitoring program. It is not likely that such higher concentrations would anywhere approach the levels specified in the National Ambient Air Quality Standards. In addition, modeling results presented presented in Section 8.0 of this report show that the predicted levels of NO_2, TSP, SO_2 and CO resulting from sources in the Prudhoe Bay area would not approach the concentrations allowed by the NAAQS even if the highest pollutant levels measured

TABLE 4-2

MAXIMUM MEASURED POLLUTANT LEVELS ($\mu g/m^3$)

IN THE PRUDHOE BAY AREA*

Pollutant	Monitor Location: Drill Site 9	Monitor Location: Well Pad A	National Ambient Air Quality Standards: Primary	National Ambient Air Quality Standards: Secondary
NO_2				
Arith. Mean*	1.6	2.5	100 (Annual)	100 (Annual)
TSP				
Geo. Mean*	6.7	14.3	75 (Annual)	60 (Annual)
24 Hr. Max+	40.0	88.0	260	150
SO_2				
Arith. Mean*	0.2	0.4	80 (Annual)	---
24 Hr. Max+	4.5	9.3	265	---
3 Hr. Max+	11.0	18.0	---	1300
CO				
8 Hr. Max+	1023	1106	10,000	10,000
1 Hr. Max+	3340	1390	40,000	40,000
O_3				
1 Hr. Max++	113.0	113.0	240	240
NMHC				
3 Hr. Max**(6-9 am)	210.0	106.0	---	---

* Period of Record (3/16/79 - 6/31/79)

\+ Not to be exceeded more than once per year

++ Ozone standard is attained if the expected number of days per calendar year with maximum hourly average concentrations is ≤one.

**Guideline

during the 3½ month monitoring program were added to these modeling results.

The ozone levels measured thus far during the on-site monitoring study should be representative of existing ozone levels in the region, and also should include monitoring periods during which maximum ozone levels are expected to occur along the North Slope. Ozone monitoring data collected by the National Oceanic and Atmospheric Administration (NOAA) at Point Barrow, Alaska for the period March 1973 through December 1978 show that maximum ozone concentrations usually occur during the months of February, March, and April with secondary maxima during the months of October and November (Oltman, 1979).

The springtime maximum occurrence noted by the researchers at Point Barrow, Alaska corresponds to the time of maximum measured ozone concentrations observed during the on-site monitoring program at Prudhoe Bay. During the month of April, Prudhoe Bay monitor sites 1 and 2 both recorded maximum ozone levels of 113 $\mu g/m^3$. This level compares closely to the maximum concentration measured by NOAA during the five year monitoring program at Point Barrow of about 100 $\mu g/m^3$. Also the average concentrations recorded in the Prudhoe Bay monitoring network, ranging from about 40 to 60 $\mu g/m^3$, correspond closely to the average concentrations measured at Point Barrow.

Mr. Sam Oltman of the Office of Geophysical Monitoring of Climatic Change at NOAA stated that based on the Point Barrow monitoring no clear causes for variations in ozone levels along the North Slope could be identified. He was unable to correlate the variations with the phenomenon of stratospheric injection or with seasonal variations in incoming solar radiation (Oltman, 1979).

Background pollutant levels for use in determining total air quality impacts on NAAQS were estimated from the data collected during the Prudhoe Bay monitoring program. In order to eliminate the influence of existing Prudhoe Bay area sources on the monitors, only those periods during which the monitors were upwind of all Prudhoe Bay sources were selected for use in the background estimation. For each pollutant, the mean of all concentrations measured during the selected periods was chosen as the background applicable for all averaging times. It was assumed that measurements occurring during periods of east-northeast winds at Drill Site 9 and west-southwest winds at Well Pad A would be representative of background conditions in the Prudhoe Bay area.

Based on these assumptions and methods, background concentrations were estimated for the two monitor sites and are shown in Table 4-3.

TABLE 4-3

ESTIMATED BACKGROUND LEVELS FOR DIFFERENT POLLUTANTS AND PREDOMINANT WIND DIRECTIONS ($\mu g/m^3$)

Predominant Wind Direction	Background Concentration NO_2	TSP	SO_2	CO	O_3	NMHC
East-Northeasterly*	1	6	0	70	47	40
West-Southwesterly**	0	9	0	180	56	<10
Background Level for Determining Total Impacts	1***	9	0***	180	56	40

* Estimated from measurements taken at Well Pad A for the period 3/16/79 - 6/31/79

** Estimated from measurements taken at Drill Site 9 for the period 3/16/79 - 6/31/79

*** Below detectability limit of instrument.

4.4 References for Section 4

Amstead, B. H., "Mean Annual Number of Days with Glaze (Freezing Rain)," in "Solar Energy Notes - Spring 1978 Class Notes," Austin, Texas, University of Texas, 1978.

Dames and Moore, Prevention of Significant Deterioration Permit Application Submitted by Atlantic Richfield Company and SOHIO Petroleum Company on Behalf of the Prudhoe Bay Unit Owners to the U.S. Environmental Protection Agency for Construction of Additional Facilities at the Prudhoe Bay Oil Field, Prudhoe Bay, Alaska, August 1978.

Huschke, Ralph E., ed., Glossary of Meteorology, Boston, MA, American Meteorological Society, 1959.

National Climatic Center, Surface Meteorological Tape for Barter Island, Alaska - TDF 1440 DATA FORMAT. Period of Record 1958-1964, Asheville, NC.

National Oceanic and Atmospheric Administration, Climates of the States, Vol. 1: Alabama-Montana, Detroit, MI, Gale Research Company, 1978.

Personal Communications with Sam Oltman, Offices of Geophysical Monitoring of Climatic Change, Boulder, Colorado, August 21, 1979.

5.0 BEST AVAILABLE CONTROL TECHNOLOGY (BACT)

The Clean Air Act requires that all new major emitting facilities be subject to the Best Available Control Technology (BACT) for each regulated pollutant. A major emitting facility or source is defined as any one of 28 category sources specified by EPA, whose uncontrolled emissions are greater than 100 tons per year and any other source with uncontrolled emissions greater than 250 tons per year. The projects described in this application do not fall on the 28 category source list. An applicant must demonstrate that BACT will be applied (Federal Register, June 19, 1978, p. 26385) to all sources of pollutants at major facilities for all pollutants of which a new facility('s) increases in allowable emissions will exceed 100 pounds per hour, 1000 pounds per day, or 50 tons per year.

Table 5-1 shows that in combination the proposed facilities will have the potential to yield a total of more than 250 tons per year of nitrogen oxides (NO_x), particulates, hydrocarbons (HC), and carbon monoxide (CO). Therefore, the proposed facilities will constitute a major stationary source of those pollutants. Furthermore, Table 5-1 shows that the facilities will have controlled emissions exceeding 50 tons per year of these same pollutants. Potential emissions for SO_2 will be less than 250 tons per year.

In a manner consistent with national and EPA Region X guidelines an analysis has been performed to determine the BACT for the proposed facilities. The conclusions are presented in Section 5.1 and the analyses are presented in Section 5.2.

TABLE 5-1

TOTAL POTENTIAL AND ALLOWABLE EMISSIONS

FOR NEW SOURCES (TONS/YEAR)

	NO_x	NMHC[1]	CO	Part[2]	SO_2[2]
Potential	22,645	744	4099	586	18.5
Allowable	NA[3]	NA[3]	NA[3]	2895	35,527

[1] Assuming all hydrocarbons are non-methane.

[2] In reality, allowable or controlled emissions of SO_2 and particulates should not exceed potential levels.

[3] Not Applicable: The Alaska SIP does not specify allowable emission rates for these pollutants. Allowable and potential emissions of these pollutants from gas heaters are the same.

5.1 Proposed Control Systems Representing BACT

The three primary types of sources of pollutant emissions at the proposed facilities will be combustion-turbines, process heaters, and fuel-storage tanks. Of the four pollutants for which BACT was determined, hydrocarbons are the only emissions potentially contributed by the storage tanks.

Nitrogen oxide (NO_x) emissions from the turbines and heaters will be kept at a minimum by burning a low organic-nitrogen bearing fuel, natural gas. The combustion chambers of the turbines will be designed to prohibit thermal-produced NO_x emissions from exceeding a concentration of 150 ppm, in the flue gas, as required by the draft New Source Performance Standards to be proposed in the near future.

Particulate emissions from the turbines and heaters will also be minimized by burning natural gas.

Hydrocarbon emissions will not be controlled, but the cold arctic temperatures will tend to inhibit the emission of hydrocarbon vapors from the fuel-storage tanks, because vapor pressures within the tanks will be lower.

Carbon monoxide emissions will not be controlled.

5.2 Alternative Systems Capable of Achieving Lower Emission Rates and Reasons for Their Rejection

5.2.1 For Combustion-Turbines

The most promising systems from the standpoint of minimizing NO_x emissions from combustion-turbines while maintaining a high fuel-to-power efficiency are the so-called dry controls being incorporated into turbine combustion chambers. One turbine-unit is presently being marketed which the manufacturer claims will meet a limit of 75 ppm with its dry control (Hansen, August 15, 1979). However, this unit is of the size commonly used by electric utilities (70 Mw) and therefore is not suitable as a compressor drive unit like those proposed for the new facilities. The largest proposed for use at Prudhoe Bay are rated at about 50 Mw.

Delivery of the larger turbine to customers will not begin until 1980 which means the production model is not commercially proven. Also, because of the remote location and hostile environment, Prudhoe Bay is not a viable place for any type of machinery which is neither designed specifically for such an environment, nor proven to be commercially reliable under such conditions.

The next best system for turbines from a NO_x emissions limitation standpoint is the injection of water or steam (EPA, September 1977, pp. 4-96). However, this control method is highly impractical on the North Slope from the standpoint of environmental impact, economic impacts, energy impacts, and engineering feasibility. The associated problems stem chiefly from the scarcity of fresh water, the extreme cold, and the fragility of the tundra. Because of these problems, extensive documentation has been compiled to support using no NO_x controls for Prudhoe Bay combustion turbines. This documentation is summarized in correspondence dated August 15, 1978, from W. P. Metz, Senior Environmental Engineer, Atlantic-Richfield Company, Alaska Region, to Mr. Paul Boys, U.S. Environmental Protection Agency, Region X. Other types of NO_x controls such as two-stage combustion are available, but serve primarily to reduce the production of organic NO_x, which is not a significant occurrence in natural gas combustion (EPA, September 1977, pp. 4-97).

Therefore, for this application the best available way to minimize NO_x emissions is to burn a fuel which contains very little organic nitrogen (EPA, September 1977, pp. 4-97). The Unit operators propose to use natural gas from the Prudhoe Bay fields as such a fuel. The gaseous nitrogen (N_2) content of natural gas from the Prudhoe Bay fields is typically 0.7 percent by volume. Though this gaseous nitrogen will partially be converted to thermal NO_x , the contribution to total thermal NO_x production will be very small when compared to the contribution of the intake air which will be 78 percent gaseous nitrogen. It is nitrogen that is bound in organic compounds in the fuel that most readily reacts to form NO_x. NO_x produced in this manner are known as organic NO_x. According to EPA's Combustion Research Branch, the firing of natural gas in turbines is likely to produce less than half as much NO_x emissions as the firing of Alaskan No. 6 fuel oil, because there will be no organic NO_x (Lanier, February and August 1979).

By firing with natural gas, the concentration of NO_x in the turbine exhaust gases will meet the drafted New Source Performance Standards (Bell, August 1979) for combustion-turbines in rural petroleum production and transportation facilities. EPA's Office of Air Quality Planning and Standards estimates promulgation by Fall, 1979 of the present draft version of these standards which require that the flue-gas concentration of NO_x not exceed 150 ppm at 15 percent excess air (Bell, August 1979).

A low NO_x emissions rate is not the only reason for choosing natural gas firing as representing BACT. If this analysis were to include firing with oil, it would show that oil firing would not only result in higher NO_x emissions, but also higher SO_2 and particulate emissions and would be less economical.

There are no superior demonstrated alternatives to gas-firing for reducing particulate emissions from combustion-turbines. Gas-firing represents the best available particulate emission control technology.

Hydrocarbon (HC) and carbon monoxide (CO) emissions from turbines can be decreased by increasing the flame temperature and the combustion chamber residence time, but this increases NO_x emissions (EPA, September 1977, pp. 3-104). Because of the relatively large quantities of NO_x produced compared to those of HC and CO, such as a trade-off would not be justifiable. Therefore, "no control" represents BACT for CO and HC.

5.2.2 For Process Heaters

As mentioned in section 5.1, BACT for the process heaters has been determined to be the use of natural gas (an intrinsically low-polluting fuel) along with normal good combustion practice and no air preheat. Use of natural gas will reduce the emissions of particulates and oxides of sulfur (SO_x) substantially, and will reduce oxides of nitrogen (NO_x) somewhat.

No alternative controls are available to reduce particulates, CO, HC, or SO_x below the levels achieved by firing natural gas. There are several systems which can theoretically be used to further reduce NO_x emissions, but it can be shown that each of these is unsuitable for the proposed facility (Evans, January 1978; Siddiqi, October 1976, pp. 94-97).

Minimizing the excess air used in the combustion process can reduce the formation of NO_x. A continuous oxygen monitor in the stack and control of combustion air flow rate is required to maintain a low excess air level without endangering the flame stability or increasing HC and CO emissions. This type of control, however, has not been proven to be reliable in the severe arctic environment. It would also require regular maintenance and calibration, to operate effectively, and would increase the demand for skilled technicians. Since many of the process heaters are in remote locations and can receive only intermittent attention from operating and maintenance personnel, the reliability of the use of excess air as a control measure is questionable. Although low excess air firing has been demonstrated effective in other situations, it does slightly increase the possibility of a flame-out. The potential results of a flame-out (explosion and/or fire) outweigh the benefits of the slight NO_x reduction.

Off-stoichiometric combustion techniques (such as staged combustion and overfire air) can also be effective at reducing NO_x emissions from fired heaters. In these processes, the primary combustion zone is fuel rich (with only 80 to 90 percent of the stoichiometric air being supplied) with combustion being completed in a fuel lean zone at lower temperatures. This technique increases the initial cost of the heater, sometimes results in lower heater efficiency, and has a slight adverse effect on flame stability. The maintenance of flame stability at the remote unattended heaters could be difficult.

Low NO_x burners in the heaters are a potential control measure. They reduce NO_x formation by better fuel atomization, fuel/air mixing, lower peak flame temperatures, an oxygen deficient primary combustion zone, and flue gas recirculation by eddies and swirling action. These burners cost more than ordinary burners and have seen application primarily in oil firing service. In addition, they often require instrumentation to monitor and control the excess air in order to operate effectively, and maintenance of these controls at remote sites requires skilled technicians and regular visits.

Flue gas recirculation has been shown effective in reducing NO_x emissions from utility sized boilers but has not been demonstrated for small process heaters. This system uses a large fan to circulate exhaust gases back to the primary combustion zone, thus lowering the peak flame temperatures by dilution. This system is expensive in terms of initial investment and upkeep. The fan imposes a parasitic power demand on the heater, and in several cases, it has resulted in vibrational problems which significantly increased maintenance.

Several more sophisticated processes are available to treat heater flue gases to remove NO_x or to convert it to NO_2.

These processes, developed for large utility boilers in Japan, would be far too expensive for use on small process heaters even if the technology were readily available. Among these processes are flue gas scrubbing, selective catalytic reduction with ammonia, and thermal reduction with ammonia. However, use of such processes results in additional solid waste and waste water handling and treatment problems.

In conclusion, firing natural gas with good combustion practice and no air preheat should be considered BACT for heaters. There is a plentiful supply of natural gas which is currently being reinjected into the ground. It's choice as an energy source for combustion is attractive both from an economic and an environmental standpoint. Other emissions controls remove, at most, only 30 to 40 percent of the NO_x and may remove as low as 10 to 20 percent due to the size of the heaters. The proposed emission reduction with the application of these controls from these units would not exceed 1.0 percent of the total emissions including existing and proposed sources (with recommended BACT) from the entire Prudhoe Bay Unit and the Deadhorse area. In addition, the harsh environment of the area causes problems related to maintenance and reliability of heater controls. Therefore, alternative approaches to BACT are not as attractive.

5.3 For Fuel Storage Tanks

Hydrocarbon emissions from the three fuel oil storage tanks can effectively be reduced to a negligible quantity by the use of vapor recovery. This type of control is expensive, relative to the benefit, and the proposed NSPS for Petroleum Liquid storage Vessels (43 Federal Register 21616, May 18, 1978) requires vapor recovery only on tanks containing a petroleum liquid with a vapor pressure greater than 11.1 psia. The fuel oil to be stored will have a vapor pressure of only about 0.0041 psia at 40°F. As can be seen in the emissions inventory presented in Section 6.0, the emissions from the fuel oil storage tanks will be negligible without vapor recovery.

The three ullage tanks will handle only crude-oil, and are intended to be used only in an emergency. It is assumed that the ullage tanks will always be empty and, therefore, no mechanical controls will be applied.

5.4 References for Section 5

Bell, Doug, U.S. EPA, Emissions Standards and Engineering Division, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, personal communication, Radian, August 15, 1979.

Environmental Protection Agency, Standards Development Branch, Standards Support and Environmental Impact Statement, Vol. 1, Proposed Standards of Performance for Stationary Gas Turbines, EPA 450/2-77-017a, Research Triangle, NC, September 1977, p. 3-104, p. 4-96, and p.4-97.

Evans, R.M. et al., Control Techniques for Nitrogen Oxides Emissions from Stationary Sources, Final Report, 2nd Edition. EPA Contract No. 68-02-2611, Task 12, EPA 450/1-78-001.

Federal Register, Vol. 43, No. 118, June 19, 1978, p. 26385.

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Lanier, W. S., U.S. EPA, Combustion Research Branch (MD-65), Research Triangle Park, North Carolina, correspondence, Radian, February 20, 1979, and personal communication, Radian, August 16, 1979.

Siddiqi, A. A., J. W. Tenini, and L. D. Killion, "Control NO_x Emissions from Fixed Fireboxes", Hydrocarbon Processing, October 1976, p. 94-97.

6.0 NEW SOURCE EMISSIONS

6.1 Methodology for Combustion Turbines

The method used to calculate potential emissions for gas turbines is based on the fuel gas composition or AP-42 emission factors. A typical fuel gas composition is presented in Appendix B.

Potential emissions of nitrogen oxides are based on proposed New Source Performance Standards for Stationary Gas Turbines (NSPS) (Federal Register, Vol. 42, No. 191, October 1977, p. 53782). Combustion calculations were performed on the fuel gas analysis (see Appendix B) with the result that 1 mole of fuel yields 31.90 moles of flue gas at 15 percent excess O_2 on a dry basis at 25°C. Operating parameters for gas turbines were obtained from manufacturers' data; fuel comsumption rates were determined from these parameters. NO_x (as NO_2) emissions were then calculated at 150 ppmv of flue gas as specified in NSPS. The equations used in performing calculations are shown in Appendix B.

Potential emissions of hydrocarbons (HC), carbon monoxide (CO), and sulfur dioxide (SO_2) are based on AP-42 emission factors for gas turbine compressor engines, Table 3.3.2-1 (EPA, AP-42, August 1977, p. 149). HC emissions are given as total hydrocarbons. The emission calculations are presented in Appendix B.

Emission factors for particulates from gas turbines are listed as not available in Table 3.3.2-1 of AP-42. Consequently, the factor from Table 3.3.1-2, composite emission factors for electric utility gas turbines was used (EPA, AP-42, August 1977, p. 146).

Allowable emissions for particulates from gas-fired turbines are based on the Alaska SIP, Section 50.050 (Environmental Conservation, Register 42, July 1972, p. 18-5). It states that particulate emissions may not exceed 0.05 grains per cubic foot of exhaust corrected to standard conditions of 70°F on a dry basis. Allowable emissions of SO_2 for gas turbines are based on the proposed NSPS (Federal Register, Vol. 42, October 1977, p. 53782). The proposed limit is 150 ppmv SO_2 in the flue gas at 15 percent excess O_2 on a dry basis at 25°C. This is the same as the proposed limit for NO_x. The annual allowable emissions for NO_x and SO_2, as presented in Table 6-1, differ because the molecular weights of the two pollutants are different. See Appendix B for the emissions calculations.

The Alaska SIP does not give flue gas concentrations from which to determine allowable emission rates for NO_x, HC, and CO. Therefore, allowable emission rates for these pollutants are not presented in Table 6-1.

6.2 Methodology for Gas-Fired Heaters

The potential emissions of all pollutants from gas-fired heaters are based on AP-42 emission factors for natural gas combustion sources, Table 1.4-1 (EPA, AP-42, August 1977, p. 39). The emissions calculations are presented in Appendix B.

The allowable emissions of particulates and SO_2 from gas-fired heaters are based on the Alaska SIP, Section 50.050 (Environmental Conservation, July 1972, p. 18-5). The allowable rate for particulates is 0.05 grains per cubic foot of exhaust corrected to standard conditions. The allowable rate for SO_2 is 500 ppm per cubic foot of exhaust corrected to standard

TABLE 6-1

POTENTIAL AND ALLOWABLE EMISSIONS FROM PROPOSED SOURCES

Source	Potential Emissions, Tons/Year					Allowable Emissions, Tons/Year				
	NO_x[1]	HC[2]	CO[2]	Part.[3]	SO_2[2]	NO_x[5]	HC[5]	CO[5]	Part.[6]	SO_2[4]
Gas Turbines										
1,400 hp.	36.2	1.2	6.8	1.1	0.02	–	–	–	5.2	50.9
3,500 hp.	90.4	3.1	16.9	2.2	0.06	–	–	–	10.0	127.2
5,000 hp.	129.3	4.4	24.1	3.1	0.07	–	–	–	14.4	181.3
22,600 hp.	584.0	19.8	108.9	14.4	0.40	–	–	–	66.1	821.5
25,000 hp.	646.0	21.9	120.5	15.9	0.44	–	–	–	73.2	908.8
26,600 hp.	687.3	23.3	128.2	17.2	0.47	–	–	–	79.0	966.9
36,000 hp.	930.2	31.5	173.5	21.2	0.63	–	–	–	97.4	1308.6
Gas Heaters	NO_x[7]	HC[7]	CO[7]	Part.[7]	SO_2[7]	NO_x[5]	HC[5]	CO[5]	Part.[6]	SO_2[8]
5 million Btu/hr.	4.1	0.07	0.4	0.24	0.01	–	–	–	1.5	17.8
10 million Btu/hr.	8.3	0.14	0.8	0.48	0.03	–	–	–	3.1	35.7
26 million Btu/hr.	21.9	0.4	2.1	1.2	0.7	–	–	–	8.0	92.8
42.5 million Btu/hr.	35.2	0.60	3.4	2.0	0.12	–	–	–	13.1	151.6
100 million Btu/hr.	82.7	1.4	8.0	4.7	0.28	–	–	–	30.8	356.8
310.5 million Btu/hr.	256.9	4.4	25.0	14.7	0.88	–	–	–	95.5	1107.9
Fuel Oil Storage Tank[9]	0.34 (fuel oil)									

[1]Based on 150 ppmv NO_2 in flue gas at 15 percent excess O_2, dry basis.

[2]Based on AP-42 emission factors for gas turbine compressor engines, table 3.3.2-1.

[3]Based on AP-42 emission factors for electric utility gas-fired turbines, table 3.3.1-2.

[4]Based on 150 ppmv SO_2 in flue gas at 15 percent excess O_2, dry basis.

[5]The Alaska State Implementation Plan (SIP) does not specify allowable emission rates for these pollutants. Hence no allowable emissions are shown.

[6]Based on 0.05 grains particulate per cubic foot of exhaust from the Alaska SIP.

[7]Based on AP-42 emission factors for natural gas combustion devices, table 1.4-1.

[8]Based on 500 ppm SO_2 per cubic foot of exhaust from the Alaska SIP.

[9]Based on AP-42 calculations, section 4.3.2.1.

conditions. The emissions calculations are presented in Appendix B and the potential and allowable emissions for heaters are presented in Table 6-1.

6.3 Methodology for Storage Tanks

The potential emissions from the three fixed-roof fuel oil storage tanks are based on AP-42 emission calculations found in Section 4.3.2.1 (EPA, AP-42, August 1977, p. 163) for breathing losses and working losses. The tanks will each hold 42,000 gallons of fuel oil. The emissions calculations are based on the following assumptions:

(1) The fuel oil has the same physical properties as those given for jet kerosene in Table 4.3-1 (EPA, AP-42, August 1977, p. 164).

(2) A typical tank has a cone roof with a diameter of 25 feet and straight sides of 15 feet, assuming that a smaller diameter tank (taller) would reduce emissions based on AP-42 Section 4.3.2.1 equations.

(3) The average fuel oil temperature is maintained at 40°F.

(4) The tanks are filled once each year and are emptied once a year (42,000 gal/yr). Since the fuel oil is for emergency use only this should be a conservative assumption.

The emissions calculations for storage tanks are given in Appendix B. The annual emissions are given in Tables 6-1 and 6-2. Applicable rates for allowable emissions from fuel oil storage tanks are not addressed in the Alaska SIP.

TABLE 6-2

TOTAL POTENTIAL AND ALLOWABLE EMISSIONS FOR NEW SOURCES (TONS/YEAR)

	NO_x	NMHC[1]	CO	Part[2]	SO_2[2]
Potential	22,645	744	4099	586	18.5
Allowable	NA[3]	NA[3]	NA[3]	2895	35,527

[1] Assuming all hydrocarbons are non-methane.

[2] In reality, allowable or controlled emissions of SO_2 and particulates should not exceed potential levels.

[3] Not Applicable: The Alaska SIP does not specify allowable emission rates for these pollutants for combustion turbines. Allowable and potential emissions of these pollutants from gas heaters are the same.

6.4 References for Section 6

Environmental Conservation, 18 AAC 50.050, Industrial Processes and Fuel Burning Equipment (b), Register 42, July 1972, p. 18-5.

Environmental Protection Agency, Office of Air Quality Planning and Standards, Monitoring and Data Analysis Division, Compilation of Air Pollutant Emission Factors, 3rd Edition, AP-42, PB 275-525. Research Triangle Park, North Carolina, August 1977, p. 39, p. 146, p. 149, p. 163, and p. 164.

Federal Register, Vol. 42, No. 191, October 3, 1977, p. 53782.

7.0 TOTAL EMISSIONS INVENTORY

To calculate the net impact of the proposed sources on the Prudhoe Bay air quality, stack parameters, and emission rates were obtained for all other sources in the Prudhoe Bay area. These include the new proposed sources of this application, existing sources in the area which requires no PSD permits, and existing sources in the area which have previously received PSD permits. With a few exceptions, the emissions rates and stack parameters of existing sources and previously permitted sources listed in this application appear exactly as presented in the PSD application presented by the Unit Operators to EPA Region X in 1978. The exceptions are 1) a correction was made in the reporting of the heights of ARCO heater stacks (sources included in the 1978 PSD permit application submitted by the Unit Operators, 2) several small existing heaters located at the gathering centers and at the power station were inadvertently not included in last years PSD but have been included in this application, 3) the turbines permitted in May 1979 for the Central Power Station were modeled as two 50 Mw units (it is presently planned to purchase four 25 Mw units instead and the total 100 Mw were modeled as four 25 Mw units in this application), and 4) stack parameter information has been updated for the North Slope Borough (previously permitted under the name NANA) waste incinerator (an existing non-increment consuming source). For the 1978 PSD application, the original inventory was compiled from the permit files of the Alaska Department of Environmental Conservation (DEC) and through discussion with that agency.

The locations of emissions sources in the Prudhoe Bay area are presented in Figure 7-1. A complete inventory of emissions and stack parameters for all sources in the area is presented in Appendix C.

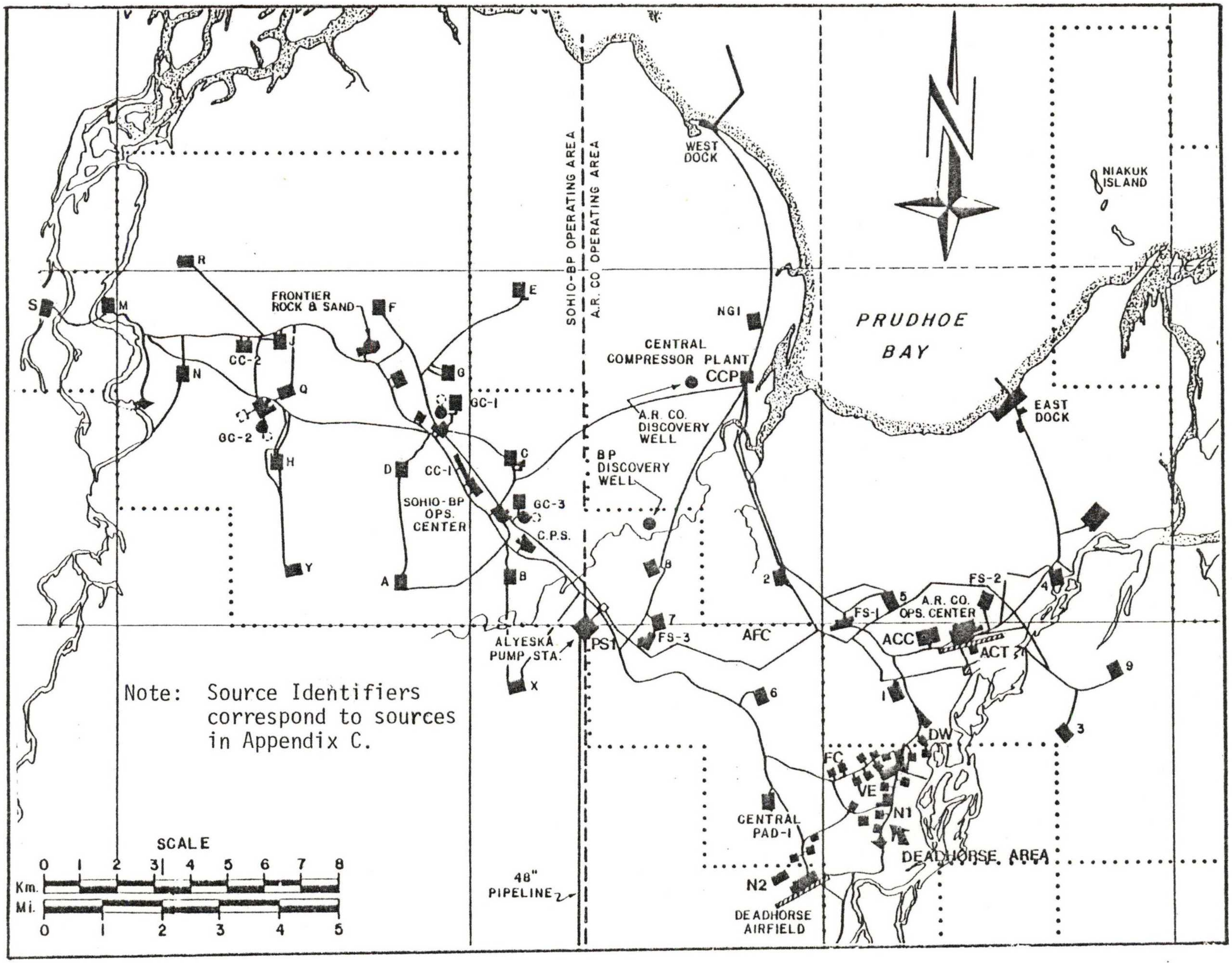

FIGURE 7-1

EMISSIONS SOURCES IN THE PRUDHOE BAY AREA

8.0 AIR QUALITY IMPACTS

8.1 Methodology

Introduction

All criteria pollutants emitted by the proposed facility in controlled amounts greater than 50 tons per year were modeled for the averaging periods for which NAAQS exist. These are NO_x, particulates, CO, and NMHC. The NAAQS which regulate these pollutants have been promulgated for annual, annual and 24-hour, 8-hour and 1-hour, and 3-hour (6 to 9 a.m.) averaging periods respectively. In the modeling analyses all NO_x is assumed to be NO_2, although in reality a much lower percentage of NO_x would be emitted as or converted to NO_2. Therefore, the assumption made here is conservative.

The incremental increases in atmospheric pollutant levels specified in the regulations for Prevention of Significant Deterioration (PSD) are defined for particulates and SO_2. However, the total potential emissions of SO_2 from the new sources are much less than 250 tons per year. Therefore, EPA regulations do not require that emissions of SO_2 from the proposed new facilities at Prudhoe Bay be examined under the PSD regulations.

Modeling Procedures

The PTMAX model was employed as an initial screening tool to determine if detailed modeling was warranted. This model is discussed in Appendix D.

The Texas Climatological Model (TCM) was selected for modeling all annual impacts. Meteorological inputs to this model consisted of a joint distribution of stability, wind speed, and wind direction for Barter Island for the period 1958 through 1964 (Appendix E). Rectangular receptor grids with 2.0 km and 0.25 km spacings were used. The 2.0 km spacing grid was employed to identify areas of maximum impacts, which were then in turn scrutinized with the 0.25 km grid.

The CRSTER and RAM models which are described in Appendix D were used to perform the detailed short-term modeling. CRSTER was used to determine the worst-case meteorological conditions and also to assess the magnitude of the impacts to be expected. One year (1964) of surface meteorological data and twice daily mixing depth data from Barter Island were selected as input to CRSTER. The worst-case meteorological conditions as determined by CRSTER were used as input data for the RAM model which was employed to assess the final 24-hour particulate, and 3-hour (6 to 9 a.m.) NMHC impacts. RAM uses a honeycomb receptor grid. Again a grid with a 1.0 km spacing between adjacent receptors was employed to locate maximum impact areas, which in turn were examined in more detail with a grid having a 0.25 km spacing.

Sources

The sources modeled consist of existing sources, sources previously permitted, and the new sources of the proposed facilities. Their emissions and sources parameters are listed in Appendix C. The sources of the proposed facilities are not in the 28 category sources specified in the PSD regulations, hence they are subject to PSD review only if the uncontrolled annual emission rates for any of the regulated pollutant is greater than 250 tons per year. A detailed air quality impact analysis is required only if the controlled emissions exceed 50 tons per year.

8.2 Initial Screening

The total allowable emissions of CO, NMHC, NO_x, SO_2, particulates (Section 6.0) for all new sources in the Prudhoe Bay were exmained to determine the need to perform air quality impact analyses. Since the controlled emissions of SO_2 from the new sources will not exceed 50 tons per year, air quality impact analyses would not be required based on EPA regulations (Federal Register, June 19, 1978).

Total carbon monoxide emissions from the new sources are very low when considered in light of the relatively high CO concentrations allowed by the primary and secondary standards. Therefore CO emissions were submitted to some simplified dispersion model screening analyses to establish the need to do more detailed air quality impact modeling.

EPA's guidelines (Federal Register, June 19, 1978) recommend that screening techniques be used to "single out, with minimum effort, those sources that clearly will not cause or contribute to ambient concentrations in excess of the National Ambient Air Quality Standards or allowable concentration increments" in order to avoid "unwarranted expenditure of resources". The UNAMAP computer model PTMAX can be used to conservatively determine short-term concentrations for all types of plume dispersion, except fumigation and downwash. This screening model was applied to carbon monoxide (CO) emissions.

The approach described below for predicting CO levels is extremely conservative and very unrealistic. However, the analysis is simplistic and, as a screening tool, useful in identifying if CO concentrations are of concern.

The CO emissions were totaled for all of the existing and proposed sources at Prudhoe Bay as shown in Appendix C. All the CO emissions were then modeled with PTMAX as if emanating from a single source. In steady-state Gaussian plume modeling, maximum ground-level concentrations predicted will always be higher if all emissions are modeled as if from one source than if multiple, similar source interaction is modeled. The sources at Prudhoe are in fact not all similar, though most of the CO emissions come from the turbines. To be conservative, all the emissions were assumed to be released from a 310 mm Btu process heater equivalent to the summation of process heaters planned for the SOHIO gathering centers. The plume rise from heaters is not as great as that from the turbines, and so predicted ground-level concentrations are greater for similar emission rates. Smaller heater stack parameters were not used because the smaller heaters produce a small percentage of the total CO emissions.

PTMAX predicted a maximum 1-hour CO level of 723 $\mu g/m^3$ during conditions of D stability and a 15 meters per second wind speed. Since this concentration falls well below the 1-hour CO standard of 40,000 $\mu g/m^3$ and the 8-hour standard of 10,000 $\mu g/m^3$ it is apparent that further air quality impact analyses are not warranted.

8.3 Determination of Area of Significant Impact

The area of significant impact is used to identify which source, in addition to the proposed new sources, must be included in the air quality impact analyses.

In the regulations implementing the PSD requirements of the Clean Air Act, the Administrator (Federal Register 43, No. 118, p. 26398) indicated that the EPA (because of model inaccuracies) did not intend to analyze impacts of a proposed facility beyond 50 km. Also, no analysis will be required for distances beyond which concentrations due to the proposed facility fall below certain "significant" levels. The area beyond which concentrations are predicted to fall below these significance levels is termed the significant impact area. Significance levels are defined in the regulation and presented in Table 8-1.

EPA requires that the significant impact area must be determined by the radius method, which consists of the following procedure: a model such as CRSTER is used to derive the isopleth of the significance level for a given pollutant and averaging time. The maximum distance this isopleth extends from the source is taken as the radius of a circle centered at the source. The area of this circle is the impact area. Figure 8-1 illustrates the procedure. It should be noted that the impact area so defined will always be greater than the significance isopleth.

The annual 1 $\mu g/m^3$ NO_2 isopleth for the proposed sources encompasses all existing and other permitted sources in the Prudhoe Bay area. Hence they all must be included in the annual impact analyses for NO_2.

TABLE 8-1

SIGNIFICANCE LEVELS FOR PSD ANALYSIS

Pollutant	Averaging Time Annual	24-Hour	8-Hour	3-Hour	1-Hour
TSP	1 $\mu g/m^3$	5 $\mu g/m^3$	N/A	N/A	N/A
SO_2	1 $\mu g/m^3$	5 $\mu g/m^3$	N/A	25 $\mu g/m^3$	N/A
NO_2	1 $\mu g/m^3$	N/A	N/A	N/A	N/A
CO	N/A	N/A	0.5 $\mu g/m^3$	N/A	2 $\mu g/m^3$

N/A = Not Applicable

Source: Federal Register 43, No. 118, p. 26398.

Since a complete emissions inventory of all existing and permitted sources in the Prudhoe Bay area has been prepared, all sources were modeled for all long- and short-term impacts and ambient air quality standards for NO_2, particulates, and NMHC.

This approach has several advantages. First, it is the most conservative and most inclusive. It also eliminates the problem of trying to define a center of the area of influence for a group of proposed sources widely dispersed.

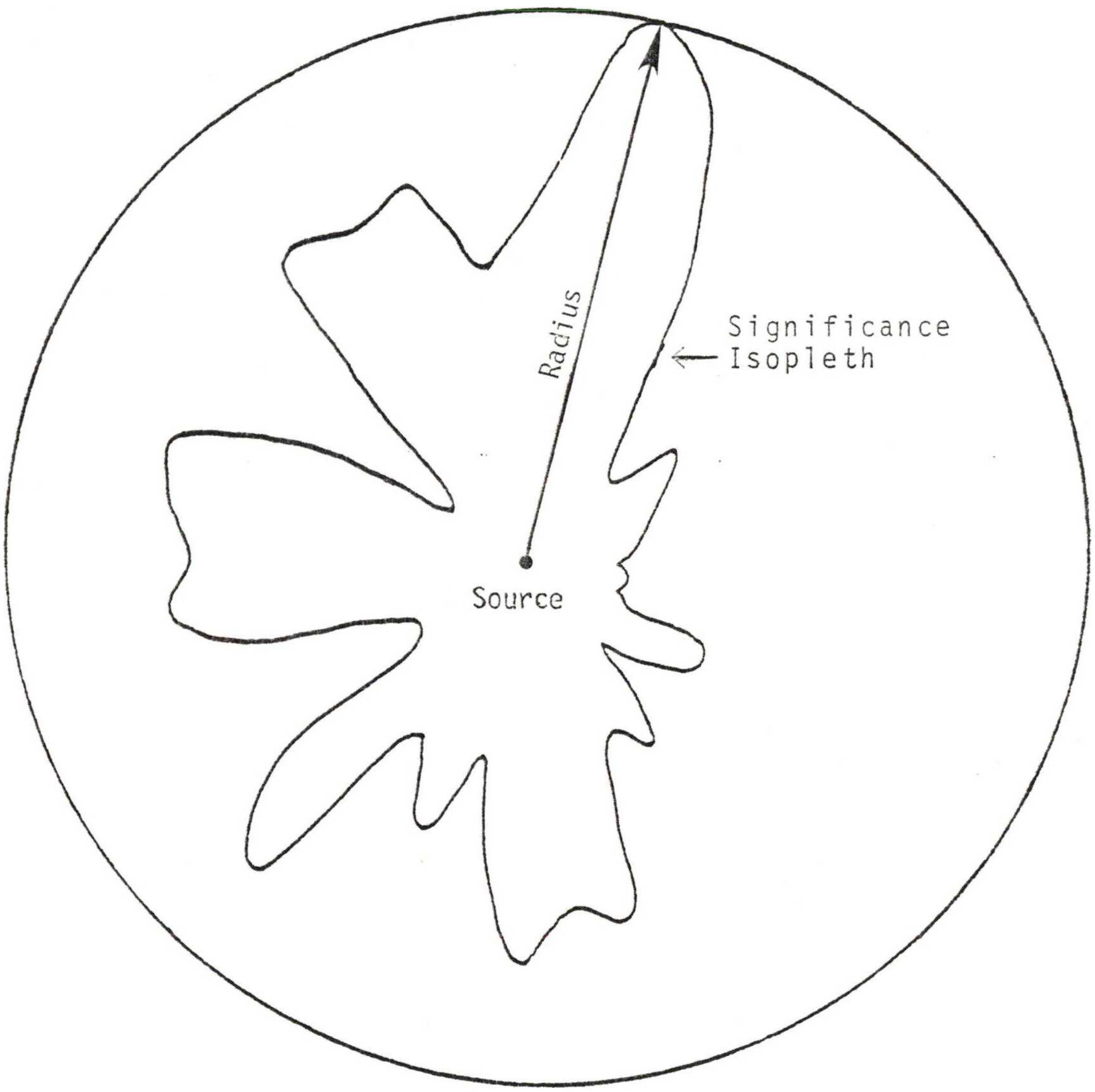

Figure 8-1. Radius Method of Determining the Area of Influence

8.4 Impacts on PSD

For the pollutants emitted in significant levels by the proposed facility, PSD increments exist only for TSP. The modeling results indicate that no violations of either the annual or 24-hour increment for particulates will occur. Also, no Class I areas will be impacted.

The sources modeled to assess particulate PSD impacts are sources permitted previously, and the sources of the proposed facilities. Predicted annual particulate levels are shown in Figure 8-2. The maximum annual concentration is 0.22 $\mu g/m^3$ which is well below the 19 $\mu g/m^3$ limit permitted by the Class II increment, and also below the 1.0 $\mu g/m^3$ annual average significance level.

Using the full year of 1964 meteorological data for Barter Island CRSTER was exercised to calculate maximum 24-hour TSP concentrations for every day of the year. Separate runs were made for the major sources of the proposed facility such as GC-1, GC-2, and FS-2, as well as Drill Pad E. Julian Day 74 (March 15, 1964) produced the largest impacts for the large emissions sources, while Julian Day 108 (April 18, 1964) maximized the impacts from Drill Pad E. However, the impacts from Drill Pad E were smaller by a factor of 3 to 4 than the impacts from the other sources. Therefore, Day 74 was selected as being the most likely to produce the maximum 24-hour impacts. The meteorological conditions which characterize Day 74 are given in Table 8-2.

Day 74 is also a day which maximizes the interactive impacts between the major sources of the proposed facility. East or west winds have the largest potential for aligning the greatest number of sources, and Day 74 exhibits a very persistent east wind.

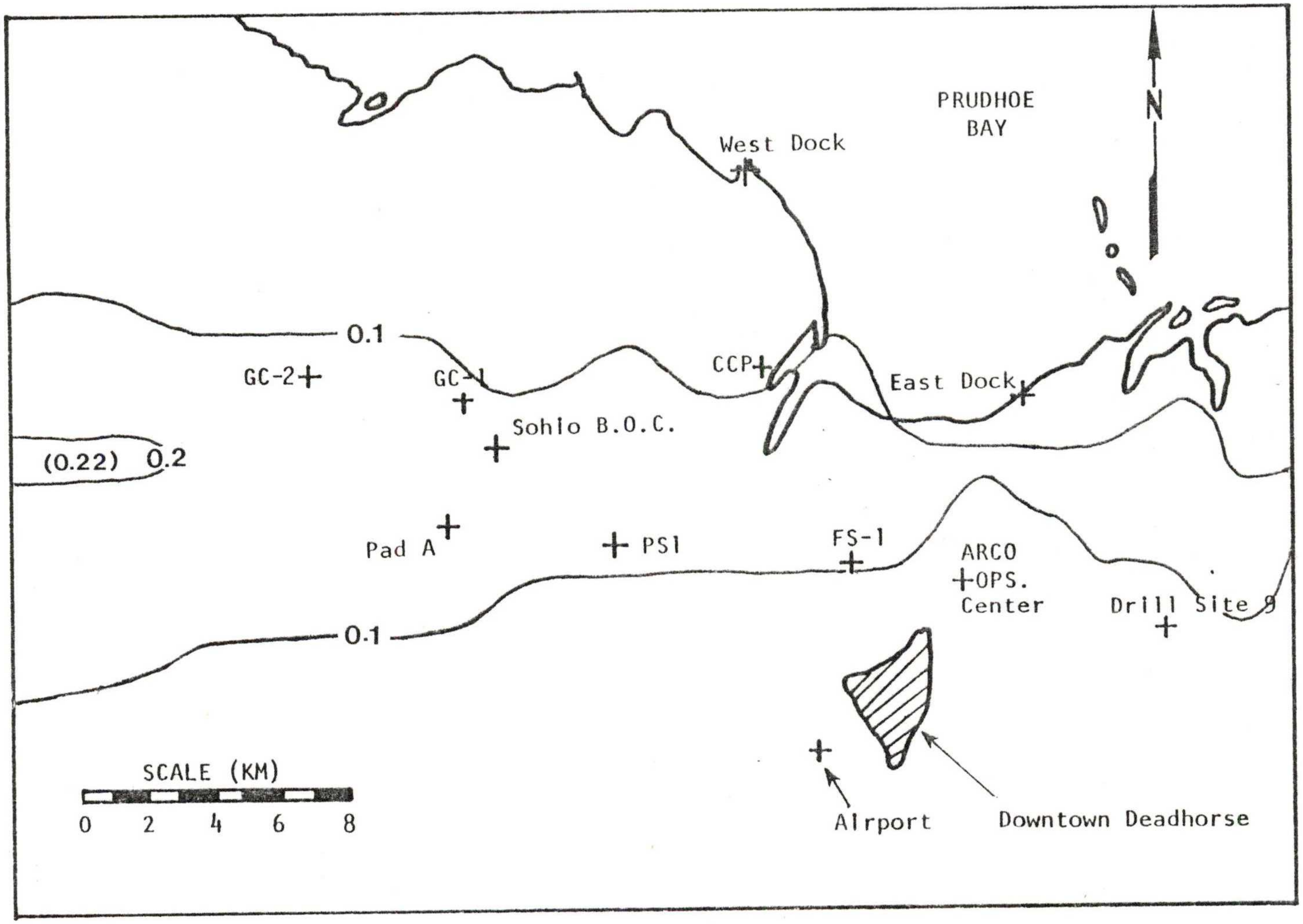

Figure 8-2. Predicted Annual Levels of Particulates for the Proposed Sources and Other Increment Consuming Sources ($\mu g/m^3$)

TABLE 8-2

METEOROLOGICAL DATA FOR DAY 74 (MARCH 15, 1964)

Hour	Direction Toward Which the Wind Is Blowing (Degrees)	Wind Speed (M/s)	Mixing Height (M)	Temperature (Deg - K)	Stability Class
1	271.00	7.72	616.10	235.37	4
2	266.00	7.20	648.32	235.37	4
3	248.00	5.66	680.54	234.81	4
4	250.00	5.14	712.77	234.26	5
5	259.00	8.75	744.99	235.37	4
6	271.00	8.75	777.21	235.92	4
7	274.00	11.32	868.00	237.04	4
8	269.00	10.80	895.83	238.70	4
9	272.00	14.40	923.67	240.37	4
10	268.00	14.40	951.50	240.93	4
11	270.00	15.43	979.33	242.04	4
12	271.00	15.43	1007.17	242.59	4
13	273.00	18.01	1035.00	243.70	4
14	273.00	20.06	1014.83	244.26	4
15	269.00	19.55	1035.00	245.37	4
16	272.00	21.61	1035.00	246.48	4
17	266.00	21.09	1035.00	245.93	4
18	267.00	18.52	1017.95	246.48	4
19	267.00	19.03	994.60	246.48	4
20	270.00	18.52	971.25	245.93	4
21	268.00	19.03	947.91	246.48	4
22	267.00	14.92	924.56	246.48	4
23	273.00	14.40	901.21	246.48	4
24	274.00	11.32	877.86	246.48	4

Resultant Met Conditions:

Wind Direction = 269.02
Average Wind Speed = 14.21
Wind Persistence = .997

Resultant Wind Speed = 14.16
Average Temperature = 241.80
Modal Stability = 4

Isopleths of maximum 24-hour TSP concentrations as determined with RAM for Day 24 are shown in Figure 8-3. The maximum 24-hour ground-level TSP concentrations is 2.1 $\mu g/m^3$ which is well below the 37 $\mu g/m^3$ Class II increment and also below the 5 $\mu g/m^3$ 24-hour significance level.

Table 8-3 summarizes the results for both the annual and 24-hour TSP PSD analyses.

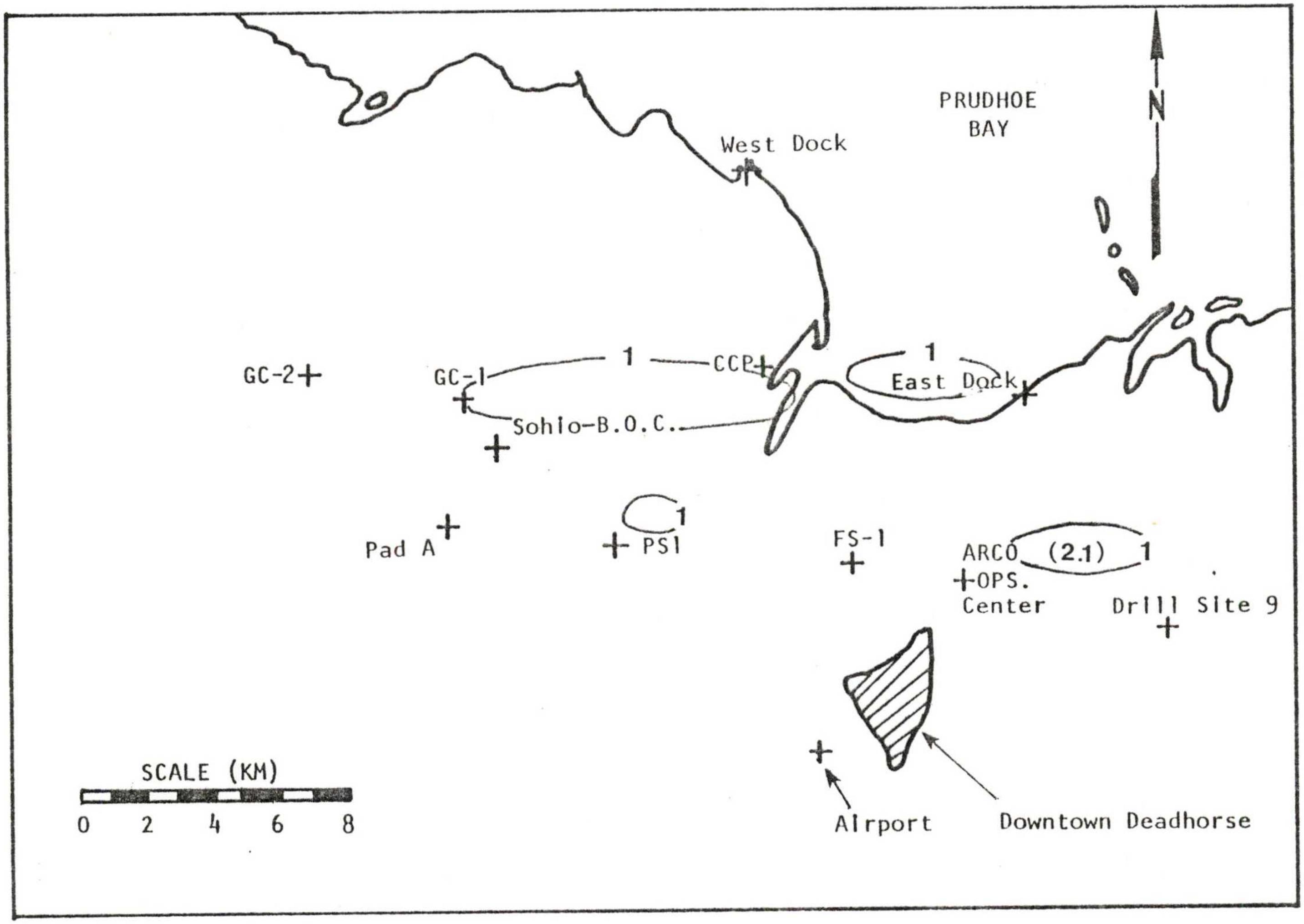

Figure 8-3. Predicted 24-Hour Levels of Particulates for the Proposed Sources and Other Increment Consuming Sources ($\mu g/m^3$)

TABLE 8-3
IMPACTS ON PSD INCREMENTS FOR PARTICULATES FOR THE PROPOSED FACILITIES AND OTHER INCREMENT CONSUMING SOURCES ($\mu g/m^3$)

	Annual Maximum	24-hour Maximum
Contribution from previously permitted sources	0.04	0.5
Contribution from proposed sources	0.18	1.6
Total PSD Increment Consumption	0.22	2.1
Allowable Class II Increment	19.00	37.0
Significance Level	1.00	5.0

8.5 Impacts on NAAQS

The modeling results indicate that neither the long- or short-term NAAQS for NO_2 or particulates will be exceeded. The maximum predicted concentrations for particulates are about 18 percent of the NAAQS. Maximum predicted short-term NMHC levels do not exceed 30 percent of the concentrations specified in the federal guideline for NMHC. The maximum predicted annual NO_x concentrations approach 70 percent of the concentration permitted by the NAAQS. It was conservatively assumed that all NO_x is NO_2 in this analysis.

The NO_2 and particulate impacts on the NAAQS were evaluated by assigning the impacts three distinct components: 1) a contribution from an anthropogenic or natural sources (termed "background", 2) a contribution from existing non-PSD or baseline sources, and 3) contributions from PSD sources (previously permitted and proposed). Even though no PSD increments exist currently for NO_2, the EPA will promulgate NO_2 PSD increments in the near future. Therefore, the previous breakdown was provided to give a better overview of the relative importance of the different components of the NO_2 impacts.

8.5.1 Annual and 24-Hour TSP Impacts on NAAQS

Natural background levels for pollutants in the Prudhoe Bay area are given in Table 4-3. For TSP a range of 6 $\mu g/m^3$ to 9 $\mu g/m^3$ is indicated. To be conservative, a value of 9 $\mu g/m^3$ was used for TSP background.

Neither the maximum annual or 24-hour PSD impacts, Figures 8-2 and 8-3, ever exceed the respective levels of significance of 1 $\mu g/m^3$ and 5 $\mu g/m^3$. This implies that no area of significant impact exists, and according to PSD guidelines, no further NAAQS impact analysis is necessary. However, for the sake of completeness, the total impact for all existing and PSD sources was determined. The resultant annual isopleths, which do not include the background of 9 $\mu g/m^3$ are shown in Figure 8-4. The maximum annual impact of 3.7 $\mu g/m^3$ is due entirely to existing sources.

The maximum impact produced by the proposed sources in conjunction with the other PSD and existing sources is predicted to occur at the receptor where the PSD increment is maximized. The total annual impact due to all sources at this receptor is 0.40 $\mu g/m^3$. This location is identical to the location of maximum annual average TSP concentrations shown on Figure 8-2.

Similar arguments also apply to the 24-hour impacts. RAM modeling of the existing and PSD sources (which include the proposed facility) show a maximum impact on 24-hour NAAQS of 3.2 $\mu g/m^3$ for Day 74 at the point of maximum PSD impact. These results are presented in Table 8-4. The annual and the 24-hour particulate impacts are less than 17 percent and 9 percent, respectively, of the levels allowed by the NAAQS.

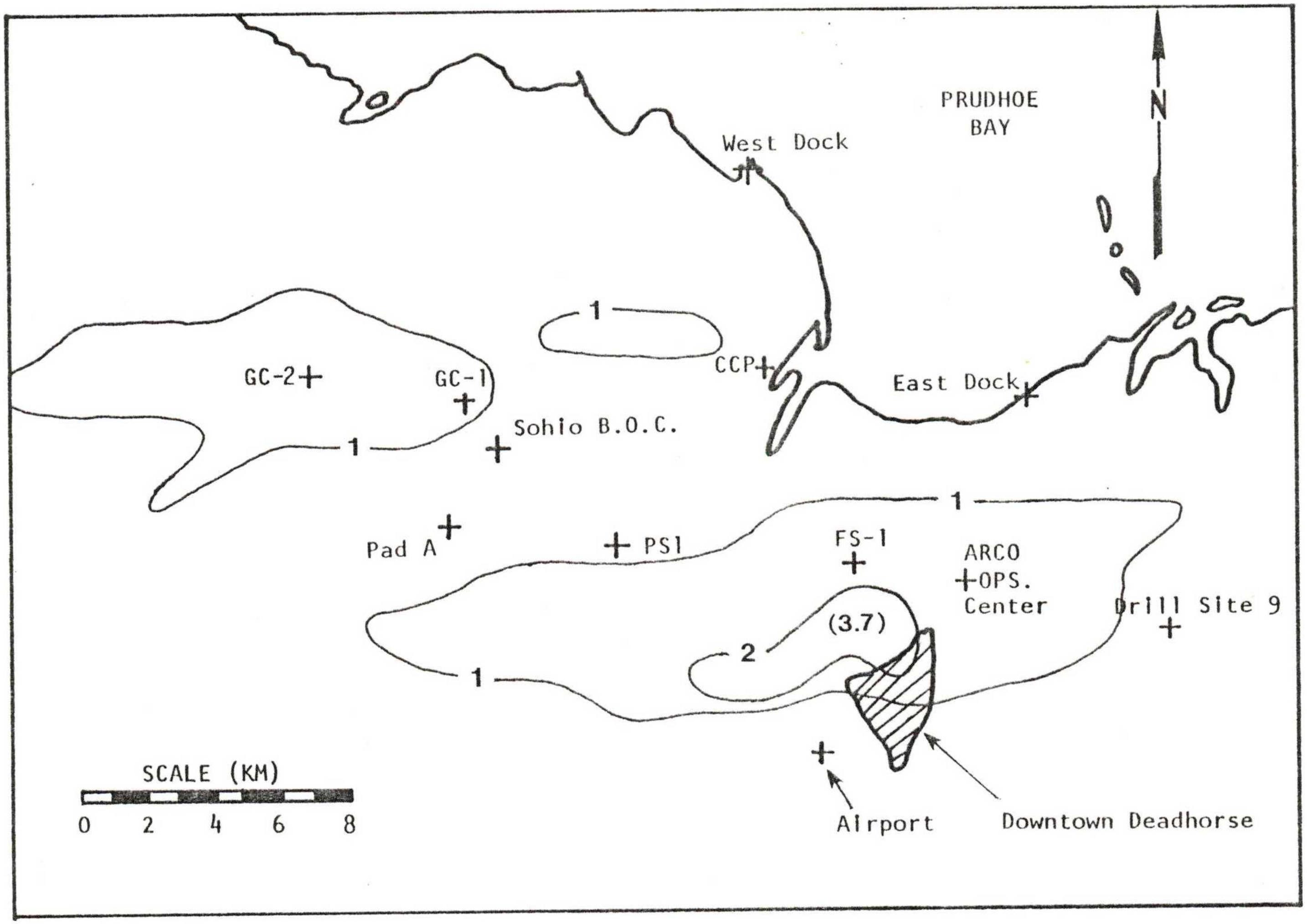

Figure 8-4. Predicted Annual Particulate Concentrations from All Sources ($\mu g/m^3$)--Background not Included

TABLE 8-4

MAXIMUM IMPACTS ON NAAQS
FOR TSP PRODUCED BY THE PROPOSED
FACILITIES AND ALL OTHER SOURCES*
($\mu g/m^3$)

	Predicted Concentration	Background	Total Computed NAAQS Impacts	Secondary NAAQS
Annual	0.40	9.0	9.40	60
24-Hour	3.2	9.0	12.2	150

* Maximums are reported for the area of maximum impacts of PSD sources. Higher impacts occur in areas of maximum impact of existing sources alone. However, the proposed sources have insignificant impacts at these locations.

8.5.2 Annual NO_2 Impacts

NO_x is the pollutant emitted in greatest quantity by the proposed facility. Currently, only an annual standard exists for NO_2.

Based on the data given in Table 4-3, a background NO_2 concentration of 1 $\mu g/m^3$ has been assumed.

From an analysis of the modeling results for NO_2, it was found that the maximum impact area for all sources (proposed, previously permitted, and existing) did not coincide with the area of maximum impact produced by the proposed sources alone. The maximum impact of all sources plus the background levels is the concentration which determines compliance with the NAAQS. However, in the current analysis this maximum impact is dominated by contributions from the existing sources. The proposed sources do not contribute appreciably. Therefore, to fully assess the impact of the proposed sources, the ambient NO_2 concentrations in the areas of their maximum impact have also been determined.

In addition, to assess the relative impacts of the proposed sources, contributions from proposed sources and from other previously permitted sources have been reported separately.

The annual NO_2 concentrations produced by the proposed sources only are shown in Figure 8-5. The maximum impacts are about 6.0 $\mu g/m^3$. Refined modeling of this area of maximum impacts with a grid having a 0.25 km spacing shows no localized impacts greater than 6.1 $\mu g/m^3$. The contributions from other permitted and existing sources to the annual NO_2 concentrations

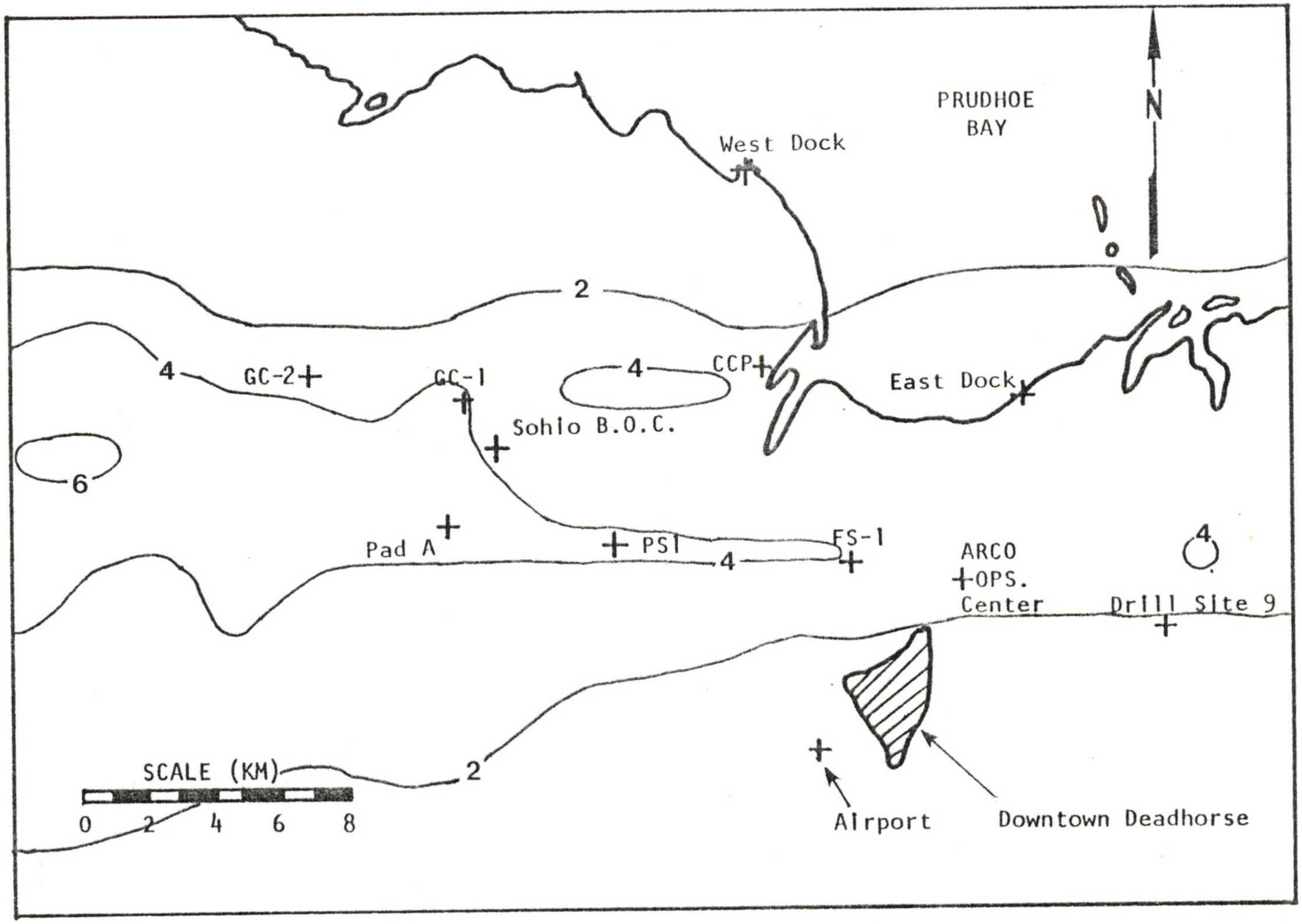

Figure 8-5. Predicted Annual NO_2 Levels ($\mu g/m^3$)
For the Proposed Sources

at this point were also determined. These are summarized in Table 8-5. The total impact of all sources including the background is 13.2 $\mu g/m^3$.

The annual NO_2 concentrations produced by all sources (proposed, previously permitted, and existing) are shown in Figure 8-6. Again, the area surrounding the maximum impact of 51 $\mu g/m^3$ was remodeled with a grid having a spacing of 0.25 km. The culpability option of TCM was also exercised. A number of localized concentrations greater than 51 $\mu g/m^3$ were found. The maximum NO_2 levels found were 68 $\mu g/m^3$ at two different receptors. Ninety five percent of these maximum levels are attributable to existing non-Unit sources. The exact contribution of the different source types is shown in Table 8-5. The total predicted maximum annual NO_2 impact, including the background is 69.4 $\mu g/m^3$.

TABLE 8-5

MAXIMUM PREDICTED ANNUAL NO_2 CONCENTRATIONS ($\mu g/m^3$)

Pollutant Sources	Concentration at Location of Maximum Impact Due to all Sources	Concentration at Location of Maximum Impact due to Proposed Sources Alone
Background	1.00	1.00
Existing Sources	67.12	4.92
Previously Permitted Sources	0.23	1.21
Proposed Sources	1.00	6.09
Total of All Sources	69.35	13.22

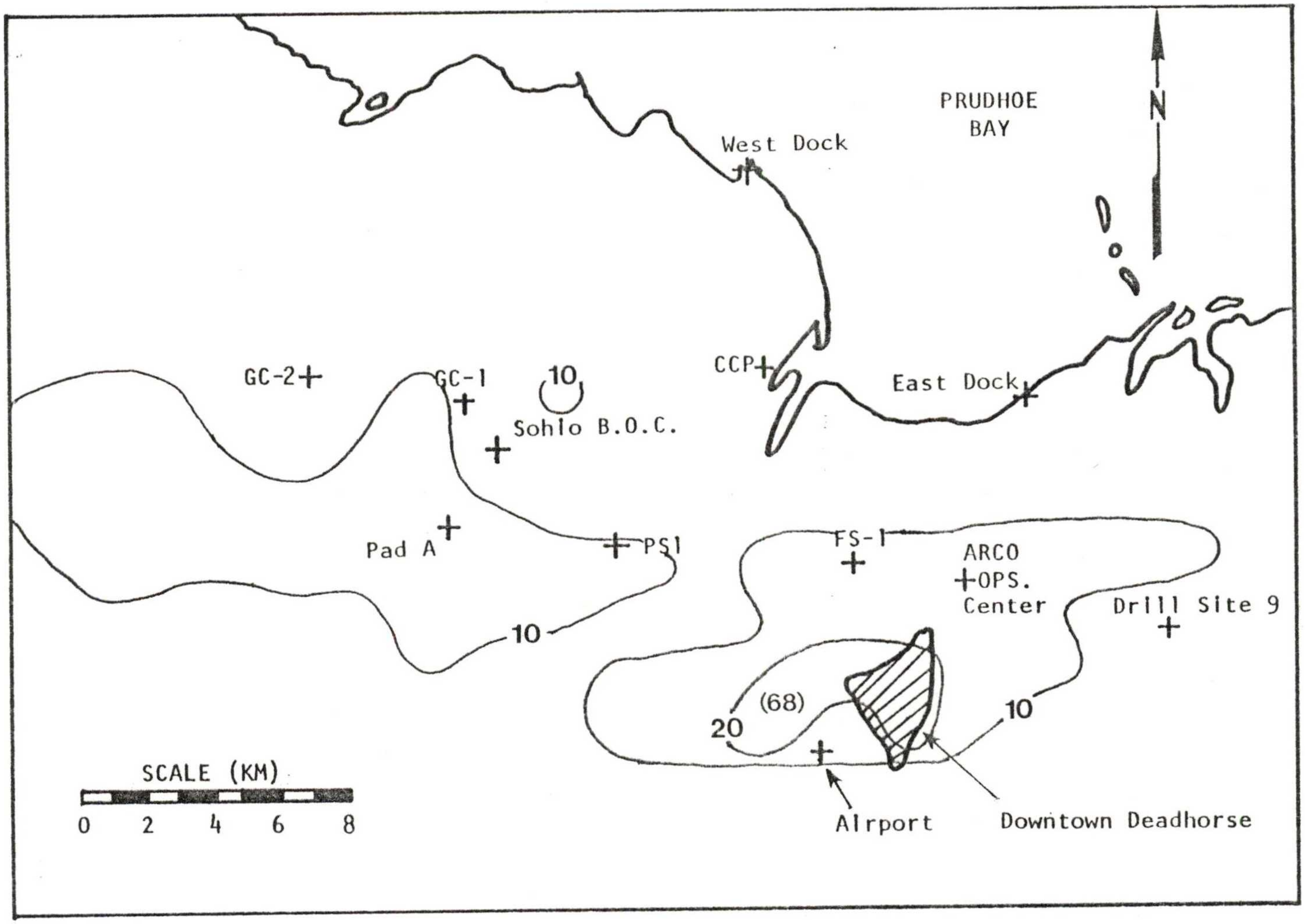

Figure 8-6. Predicted Annual NO_x Levels ($\mu g/m^3$) for all Sources -- Background not Included

8.5.3 Non-Methane Hydrocarbon Impacts

The existing federal guideline for non-methane hydrocarbons serves as an index for assessing compliance with the NAAQS for ozone. In this study the total hydrocarbon emissions from all existing and proposed sources in the Prudhoe Bay area were modeled to calculate maximum 3-hour (6 to 9 a.m.) levels for comparison to the federal guideline. A background NMHC level of 40 $\mu g/m^3$ (Table 4-3) was assumed.

Maximum ozone concentrations, however, were not calculated through dispersion modeling predictions for several reasons. First the EPA-published Compilation of Air Pollution Emissions Factors (AP-42, Section 3.3.2) states that, on the average, non-methane hydrocarbon emissions make up only 5 to 10 percent of the total hydrocarbon, from heavy-duty, natural gas-fired turbines. Specifically, the natural gas composition reported in Appendix B, p. B-1 demonstrates that methane (column 4) and other short-chain hydrocarbons comprise the largest mole percent of the fuel. For the purposes of comparing predicted hydrocarbon levels to the federal guideline, it was assumed in this study that all hydrocarbons emissions are non-methane. Therefore the calculated emissions and predicted concentrations are conservatively high. In reality then, the potential NMHC emissions from the proposed new sources should be much less than the calculated total hydrocarbon emissions of 739 tons per year (Table 6-2) and, in fact, should be less than 250 tons per year.

Secondly, because of its location at high latitudes, Prudhoe Bay receives relatively little incoming solar radiation, even during the summer months. This is reflected in the monitoring data collected at Point Barrow which shows no summer ozone maximum as is often measured at monitoring sites located at lower latitudes. Therefore, there is no clear justification for estimating ozone levels at Prudhoe Bay by modeling the photochemical reactions of non-methane hydrocarbons with other ozone precursors.

CRSTER runs were made for the major hydrocarbon emitters of the proposed and previously permitted increment consuming sources. The CRSTER summary lists the fifty 3-hour time periods which produce the maximum 3-hour impacts for a given year. Of these 50 only 2 correspond to time period 3, which is 6 to 9 a.m. For these two, Day 15 (January 15, 1964) produced the larger impact and was selected for the 3-hour impact analysis with RAM. A number of other 3-hour periods for this day also appear in the list of the highest 3-hour concentrations, which lends additional credence to selection of day 15. The meteorological conditions for time period 3 are summarized in Table 8-6.

The maximum 3-hour NMHC impact of 9.6 $\mu g/m^3$ was determined by modeling all existing, and proposed sources with RAM. Seventy-seven percent of this impact is attributable to the existing source, ARCO P-324, a set of turbines which have the largest hydrocarbon emission rate of all sources permitted and existing. The total impacts are summarized in Table 8-7. The maximum hydrocarbon emission rate for the proposed new sources is smaller by a factor of 4 than that of ARCO P-324, while the remaining stack parameters are comparable. Therefore, the impacts from the proposed new sources will be less than the total impacts reported in Table 8-7. Since ARCO P-324 does not threaten the NAAQS, neither should the proposed sources.

TABLE 8-6

METEOROLOGICAL DATA FOR JANUARY 15, 1964, PERIOD 3

Hour	Direction Toward Which the Wind is Blowing (Degrees)	Wind Speed (M/s)	Mixing Height (M)	Temperature (Deg - K)	Stability Class
7	82	15.4	495	250	4
8	79	15.9	507	250	4
9	80	17.0	519	250	4

TABLE 8-7

MAXIMUM 3-HR IMPACTS ON GUIDELINE FOR NMHC

Predicted Maximum 3-Hr NMHC Impact ($\mu g/m^3$)	Background ($\mu g/m^3$)	Total NMHC Impact ($\mu g/m^3$)	3-Hour Guideline (6-9 am) ($\mu g/m^3$)
9.6	40.	49.6	160

8.6 Impacts of Downwash

The stack heights of the proposed facilities will be lower than the Good Engineering Practice (GEP) height that is calculated from the empirical equation provided in the proposed stack height rules of the January 12, 1979 Federal Register. Because of the low stack-to-building height ratio (approximately 1 to 1 at the gathering centers), EPA Region X requested that the Unit address downwash for the proposed combustion-turbines and gas heaters.

Use of the following methods of accounting for downwash were discussed and agreed upon at the pre-application meeting. From turbine plumes, the effective intermediate and final plume heights as predicted by the Briggs plume-rise equations which are part of the EPA models, would be multiplied by 0.7 for periods of unstable or neutral atmospheric stability. This plume-rise reduction factor accounts for the entrainment of cooler ambient air being forced into the plume by the normally horizontal wind arching over the turbine housing. The effects of building wakes on process-heater plume dispersion would be accounted for by Huber's method of enhancing dispersion coefficients (Huber, 1979). A description of these methods for treating downwash and the modification of the EPA models used in this study to include these treatments are discussed in Appendix D.

To determine the impact of the downwash of heater plumes, the Unit complex with the greatest number of proposed new heaters and the greatest total heater NO_x emissions was examined. Therefore, the five heater stacks proposed at the Gathering Center Number 2 were subjected to downwash modeling. Since the impacts of downwash on ground-level pollutant concentrations should be significant only within short distances of sources (less than about 1.0 to 2.0 kilometers downwind), the interactions among downwashed plumes produced from new sources at separate locations in the Unit were not examined.

From the other modeling analyses reported in this study, it was determined that, compared to other pollutants, emissions of NO_x had the most significant impact on a primary or secondary NAAQS. Therefore, NO_x emissions were modeled in the downwash analyses. In this analysis it was assumed, for conservatism, that all NO_x was converted to NO_2.

First, a stack building configuration was assumed, because final dimensions and exact locations for the new facilities have not yet been definitized. Based on an examination of the geometry of existing facilities, conservative building dimensions were chosen for the downwash analysis. Existing heights of buildings containing heaters at gathering centers and flow stations are 18.3 meters or less, so a building height of 18.3 meters was assumed. As the building height increases, the maximum ground-level concentrations predicted by the inclusion of Huber's equations in the models became larger. Therefore, the assumption of an 18.3 meter height is conservative.

A minimum building length was assumed for the downwash analysis because Huber's equations show that the predicted concentrations are inversely proportional to building length. Stacks are spaced approximately 14 meters apart along buildings at existing gathering centers and this stack spacing was assumed for the downwash analysis. Since five new heater stacks will be located at Gathering Center 2 a conservative building length of 60 meters was assumed.

The RAM model was applied in this analysis and altered to include Huber's equations. A set of 23 receptors extending downwind of the stack with the greatest emissions and aligned normal to the building side was input to the RAM model. The first three receptors were spaced ten meters apart starting at a distance of 70 meters from the building and the remainder were spaced 100 meters apart out to a distance of two kilometers.

Meteorological inputs consisted of twenty combinations of stability classes and wind speeds likely to induce downwash. These included the Pasquill-Gifford B, C, D, E, and F stabilities and wind speeds of 3 to 17 meters per second. Stability Class A was ignored because of a tendency of Huber's method to decrease rather than increase concentrations beyond the immediate source area and also because A stability rarely occurs in the Arctic. Severe downwash is not likely to occur at wind speeds of less than three meters per second (EPA, October 1977).

The program was executed both with and without Huber's modifications for various stack heights. Results showed that with downwash the maximum 1-hour NO_2 level reached 186 $\mu g/m^3$ at a distance of 70 meters from the building. This compares to a predicted NO_2 concentration without downwash of 0 $\mu g/m^3$ at the same location, under the same dispersion condition (D stability, 17 miles per second wind speed). Annual modeling results (without downwash) show that the new heaters at Gathering Center 2 add only 2 to 3 $\mu g/m^3$ at the receptors immediately adjacent to the complex. This compares to a total predicted annual NO_2 concentration of about 7 to 10 $\mu g/m^3$ in the immediate vicinity of the gathering center and due to all sources. If it were conservatively assumed that the ratio of maximum 1-hour to annual levels were 5 to 1*, then the total annual NO_2 concentrations at 0.7 kilometers downwind of the new GC-2 heaters should not exceed about

*Larson's (1971) data shows that the ratio of maximum 1-hour to annual pollutant levels can range from about 40:1 to 70:1. These data were obtained from air quality monitoring programs conducted from 1962 to 1968 at 8 major cities in the United States.

40 μg/m³. At distances beyond 0.3 kilometers from these sources model predictions show that the consideration of downwash results in maximum 1-hour NO concentrations equal to or lower than those predicted with no downwash. Therefore, the NAAQS of 100 μg/m³ (annual average) for NO_2 would not be threatened as a result of downwash generated in the wake of the gathering center module.

8.7 References for Section 8

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9.0 IMPACTS ON SOILS AND VEGETATION

The pollutants of major concern with respect to impacts on soils and vegetation are total suspended particulates, oxides of nitrogen and NO_2 converted to particulate nitrates. In general, surface soils and natural vegetation are expected to act as a sink for most of these atmospheric pollutants from the proposed Prudhoe Bay oil field areas. That is, the surface soils and vegetation normally remove a portion of the atmospheric pollutants by surface adsorption and other processes.

9.1 Soils

Soil Characteristics

The Arctic coastal plain province in which the Prudhoe Bay sites are located constitutes a relatively large, uniform landscape unit. It is characterized by low topographic relief, numerous lakes and ponds, polygonalized ground-pattern, and a non-integrated drainage system of numerous meandering streams (Black, 1969, pp. 283-299; Brown et al., 1970, p. 148; Brown et al., 1971, p. 282). Permanently frozen ground underlies the entire region with the depth of the active layer (maximum depth of thaw) commonly being no more than 1.5 to 3 feet.

Soils characteristics of cold temperatures and poor drainage dominate, most of which are Inceptisols (tundra and half-bog soils) with Histosols (bog soils) being the most common associates (Brown, 1967, pp. 686-691; Brown, 1969; Drew et al., 1961, pp. 109-116).

Most of the tundra soils are probably Pergelic Cryaquepts and most of the half-bog soils are probably Pergelic Cryohemists and Pergelic Cryosaprists (Gersper et al., 1975, pp. 737-744)

At an international level, the soils of this area have been classified as Gelic Gleysols (UNESCO, 1975) of the Coastal Plain Province. Much greater areas of Gelic Gleysols are believed to occur as subdominant associates of the very extensive areas of Gelic Regosols occurring within the Arctic.

These soils comprise a wide variety of textures and parent materials ranging from coarse glacial till and out wash to a variety of marine sediments. The thin solum and weak profile development is mainly the result of the severity of the Arctic climate, the slow pedologic processes and the presence of permafrost.

In general, these soils reflect conditions of wetness. They are high in organic matter, strongly acid and may have low base status. High moisture contents, low temperatures, and reducing conditions prevail. The soils are underlain by perennially frozen ground, with maximum depth (UNESCO, 1975) of thawing about two feet. Generally, a rather thin histic horizon overlies a silty clay loam mineral horizon. The mineral horizons are admixed with humidifed peaty material which often occurs in sufficient quantity to qualify them as histic. Often a distinctively peaty layer is encountered at a depth of eight inches or so.

Maintenance of vegetative cover for wildlife sustenance and preservation of equilibrium between active and permafrost layers poses important problems in management. The effects of destroying protective surface cover, with consecutive deepening of the saturated active layer by thawing of the underlying permafrost, has been shown to have drastic and permanent effects on the natural ecological balance (UNESCO, 1975).

Impacts on Soils

As mentioned before soils act as a significant sink for both NO_x and particulates, all of which are removed from the air and absorbed on the soil and plant surfaces. The rate of adsorption is dependent upon distance from the source, their concentrations in the air, soil properties, density of vegetation cover, and prevailing hydrological and meteorological conditions.

The end product of soil sorption is nitrate. Maximum predicted annual concentrations of NO_2 would reach about 60 - 70 $\mu g/m^3$. The maximum 24-hour particulate levels may reach 2 $\mu g/m^3$ and annual particulate levels would be less than 0.5 $\mu g/m^3$.

It appears that the quantities of nitrates, thus added to the soil and assimilated into soil-plant system will be insignificant as compared with that normally present in these soils. Thus the amounts of pollutants added in the vicinity of the Prudhoe Bay Oil Field should exert a negligible impact on the soils of the area.

9.2 Vegetation

In general, plant growth in the Prudhoe Bay area occurs only during a three-month period (June through August) when the upper portion of the permafrost has thawed. The severe climatic environment found in this area has restricted the number of native plant taxa to approximately 70.

Vegetation Communities

A total of only four major vegetation communities have been defined that occur within the area. The wet sedge meadow community is the most prevalent while the aquatic lake community consistutes much of the remainder. Floodplains and cutbank communities are restricted to the area immediately adjacent to the Sagavanirktok and other rivers. Inland the elevation increases, drainage is improved, and the vegetation community changes to a cottongrass meadow. Lists of plant species associated with each community and adapted from Spetzman (1959) are shown in Appendix F. This type of information is provided at the request of the Alaska DEC.

Impacts on Vegetation

There is at present no recreationally or agriculturally valuable vegetation located in the vicinity of the proposed facility. It can be expected that the area possesses wildlife value, but that value should decrease in proximity to the facility due to the level of human presence. The value of the existing vegetation communities adjacent to the facility would be measured more in esthetics, and the function of the vegetation in substrata stabilization, hydrologic, and erosion characteristics.

There is currently no available information on the tolerance levels of the high arctic plants for criteria air pollutants. The probable impacts of the proposed facility can, however, be inferred from the tolerance levels determined for plants native to lower latitudes. Table 9-1 has been taken from Heck and Brandt (1977) and indicates the threshold level for acute toxicity to plants. Comparing the lower range for NO_2 effects on sensitive plant taxa, 3,000 $\mu g/m^3$; the predicted annual levels of 60 - 70 $\mu g/m^3$ would indicate no acute effects could possibly be expected.

Chronic effects from long-term exposure may be extremely diffucult to either define or quantify. Long-term (22 days) exposure to low levels of NO_2 (950 $\mu g/m^2$) has been reported to result in reduced productivity of a sensitive plant species (Jacobson and Hill, 1970). The levels of pollutant tested by far exceed the expected concentrations resulting from around the proposed facility. Although chronic effects due to long-term exposure to extremely low levels of NO_x cannot be ruled out entirely; the possibility of their occurrence is remote.

TABLE 9-1. NITROGEN DIOXIDE: PROJECTED POLLUTANT CONCENTRATIONS FOR SHORT-TERM EXPOSURES THAT WILL PROVIDE ABOUT FIVE PERCENT INJURY TO VEGETATION GROWN UNDER SENSITIVE CONDITIONS[1]

Exposure Time (hours)	Concentration ($\mu g/m^3$) Producing Five Percent Injury by Plant Susceptability Groupings		
	Sensitive Plants[2]	Intermediate Plants	Resistant Plants[3]
0.5	11,502 - 23,004	19,170 - 47,925	≥ 38,340
1.0	5,751 - 19,170	17,253 - 38,340	≥ 34,506
2.0	4,793 - 14,378	13,419 - 28,755	≥ 24,921
4.0	3,834 - 11,502	9,585 - 23,004	≥ 19,170
8.0	2,876 - 9,585	7,668 - 17,253	≥ 15,336

[1]Heck and Brandt (1977).

[2]Example: nitrogen dioxide; alfalfa, barley, cotton, pine, and squash

[3]Example: nitrogen dioxide; corn, oak, cantaloupe

The predicted incremental increases in maximum annual and 24-hour total suspended particulate levels are much lower than the significance levels of 5 $\mu g/m^3$ and 1 $\mu g/m^3$, respectively for these averaging periods. These levels are far below those considered to have detrimental effects on vegetation in the area.

9.3 References for Section 9

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10.0 IMPACTS ON VISIBILITY

Particulate matter of small diameter or aerosols formed by the conversions of SO_2 and NO_x emissions to nitrates and sulfates could potentially cause some impairment to the visibility in the Prudhoe Bay area. However, the total increase in emissions of particulate matter of all size ranges should be less than 130 tons per year as a result of the proposed new sources. In addition maximum incremental increases in 24-hour and annual TSP concentration should both be less than 2 $\mu g/m^3$. Therefore, the emissions of additional particulates should not significantly impact visibility in the area.

Enhancement of fog and ice fog formation in the study area may result from the proposed plant plumes, exhausts from the associated additional vehicles and buildings, and the respiration of the increased number of persons in the area. These additional fogs and ice fogs may result in an incremental reduction in visibility in the Prudhoe Bay area.

Meteorological observers at the Deadhorse Airport have noted enhanced fog and ice fog occurrence in the settlements and contractors' camps in the Deadhorse area. Weather forecasts in the winter sometimes include mention of ice fog development in the camps. These ice fogs have been observed to advect downwind from the camps, and according to meteorological observers, the Deadhorse Airport sometimes receives ice fog created or enhanced in development by the settlement immediately to the northeast.

Based on the most frequent wind directions shown on the annual wind rose for the Deadhorse Airport (Figure 4-3), any significant incremental impairment of visibility by fog or ice fog resulting from the proposed new sources should be restricted primarily to the Prudhoe Bay oil field although enhanced visibility impairment may occur in the vicinity of the Deadhorse area and the ARCO Base Camp airstrip.

A thick haze is visible over the Arctic Ocean each spring (Kerr, 1979). Visibility aloft is often reduced from more than 100 kilometers to less than 10. The cause(s) of the Arctic haze is not certain, but long-range transport of sulfates generated from European industry is suspected. Some haze is likely to occur in the immediate Prudhoe Bay area as a result of the new facilities, but should not have a discernible effect on the widespread Arctic haze.

To be conservative in determining impacts on ambient air quality standards, the emissions of nitrogen oxides (NO_x) from the new facilities are all assumed to be nitrogen dioxide (NO_2). The largest portion (probably greater than 90 percent) will actually be nitric oxide (NO) which is a colorless gas (Ozkaynak et al., 1979). However, NO reacts in the atmosphere to form NO_2, a yellow-brown gas, and nitrates (NO_3^-), both of which may impair visibility (Latimer and Bergstrom, 1979). Rudolf Puschel of NOAA has confirmed (1970) that NO_x emissions from a refinery are rapidly converted to nitrate particulates. The diameter of the particles mostly exceeds 0.5 microns, and the particles do cause visibility impairment. However, unlike sulfate particles, the nitrate particles quickly agglomerate to a size which falls out of the atmosphere either as dry matter or as precipitation nuclei. Because of this rapid fallout, it seems unlikely that the NO_x emissions of the proposed facilities would affect visibility outside the Prudhoe Bay area.

The oil development on the North Slope was originally suspected of contributing to the Arctic haze, but is no longer considered to be a significant factor (Shaw, 1979). The haze has been reported since the 1950s, well before the oil development began. Vanadium and manganese are found in the haze particles, but are almost nonexistent in fuel-oils burned in Alaska. They are, however, abundant in the fuels burned in Europe and the contiguous United States.

Incremental impacts on the frequency and severity of reduced visibility are likely to be insignificant compared to any impacts resulting from existing sources. Furthermore, the areas of major concern with respect to visibility impairment are the PSD Class I areas. No Class I PSD areas are located within 900 kilometers of the Prudhoe Bay area. Therefore, no impact on visibility in Class I areas is expected.

10.1 REFERENCES FOR SECTION 10

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11.0 IMPACTS OF CONSTRUCTION AND GROWTH

11.1 Construction

Due to the harsh climate on the North Slope, all of the proposed equipment will be fabricated in the contiguous United States. The equipment will be fabricated in modular components, barged north during the summer months, and installed on site. In addition, these new modules will be installed on existing or expanded gravel pads. The only construction impacts on air quality consist in the relatively minor amounts of pollutants emitted from trucks, small construction machinery, and supporting equipment. These engines emit minor amounts of hydrocarbons, sulfur dioxide, carbon monoxide, nitrogen oxides, and particulate matter. The contaminants would be expected to cause localized, temporary effects upon existing air quality, but are not expected to cause any adverse effects beyond the Prudhoe Bay area.

Fugitive dust emissions would probably be the most noticeable impact during construction. The amount of dust would vary from day to day, depending on the level of activity and the weather. Overall, fugitive dust from construction activities should add only minimally to existing background particulate levels in the area. Various control techniques will be used as necessary to meet state criteria, which specify that reasonable precautions must be taken to prevent particulate matter from becoming airborne.

11.2 Growth

After construction and start-up of the new facilities, it is anticipated that there would be little growth in supporting industries to the Prudhoe Bay area by the Unit Owners or others. Consequently, the proposed new facilities are not expected to have a pollution impact other than that discussed in this application.

Increases in living quarters or traffic resulting from the enlarged work force at the Prudhoe Bay oil field will be small. The permanent total work force required to supervise, operate, and maintain the new facilities is estimated to be about 100. This compares to an existing work force, present at any one time at Prudhoe Bay, of about 3000. This increase in population is not considered significant from an air quality impact standpoint.

APPENDIX A

ANALYTICAL ASSUMPTIONS

A. Existing Air Quality

1. Air quality data collected from March 16, 1979 until June 30, 1979 during the on-site monitoring program is acceptable for use in establishing the existing air quality for the Prudhoe Bay area.

2. Concentrations measured at Well Pad A during west-southwesterly winds and at Drill Site 9 during east-northeasterly winds represent background concentrations (those which are uninfluenced by Prudhoe Bay facilities).

B. Emissions

1. Turbine models have not yet been selected, so emission rates are based on average emission factors for turbines and the given power requirements.

2. Emission rates have not been measured for these particular process heaters, so emission rates are based on emission factors for natural gas combustion devices and their given heat inputs.

3. Emission rates for fuel oil storage tanks have been based on emission factors for average tank temperature of 40°F.

4. The ullage tank will be empty except for emergency use.

5. The flare facilities for separator off gas will not be used except in emergencies.

C. Air Quality Impacts

1. To screen out carbon monoxide (CO) as a pollutant requiring refined modeling, CO emissions were calculated and totaled for all existing and proposed sources and were assumed, for conservation, to be released from a single heater.

2. All oxides of nitrogen are assumed to be nitrogen dioxide (NO_2) even though conversion of NO to NO_2 may actually require more time than the time plumes use to disperse.

3. All hydrocarbon emissions are assumed to be NMHC.

4. For each pollutant, the higher background concentration of the two monitor sites was used as the background for modeling. (See Assumption A-1.)

5. The meteorological conditions causing highest CRSTER-predicted concentrations from important single sources would also cause the highest concentrations to be predicted when modeling all the sources with RAM.

6. To avoid CRSTER preprocessor program logic problems, mixing heights were linearly interpolated between successive afternoon mixing height values on days of no sunrise or sunset.

7. To avoid CRSTER preprocessor program logic problems, sunrise was set to 0000 hrs and sunset to 2400 hrs for summer days when neither sunrise nor sunset actually occurs.

8. Downwash for process heaters is adequately simulated beyond three building heights downwind by Huber's technique (Huber, 1979).

9. Proposed Gathering Center-2 heaters will produce the worst downwash case.

10. Downwash for turbines with high exhaust temperatures is conservatively simulated by restricting modeled intermediate and final plume heights to seven-tenths of Brigg's Plume Rise for unstable and neutral conditions.

11. Conservative building dimensions for a downwash analysis of Gathering Center-2 would be 18.3 meters high and 60 meters long.

12. All emitting facilities will operate continuously year round.

13. All emissions sources within a certain complex (gathering center, flow station) can be assumed for modeling purposes, to be located at the single set UTM coordinates reported for the complex.

14. Meteorological data collected at Barter Island, Alaska is acceptable for use in modeling air quality impacts at Prudhoe Bay.

15. Standard EPA-recommended models (TCM, CRSTER, PTMAX, RAM rural) with the plume rise and mixing height modifications discussed in Appendix D are suitable or at worst, conservative in their ability to accurately

predict pollution concentrations from point sources in the Prudhoe Bay area.

16. Emissions and stack parameters for existing non-Unit emissions sources in the Prudhoe Bay area do not differ, except as noted, from the values reported in the 1978 PSD permit application prepared by the Unit Operators.

APPENDIX B

EMISSIONS CALCULATIONS

APPENDIX B - EMISSIONS CALCULATIONS

Typical fuel composition supplied by SOHIO:

Component	Molecular Weight	Mole %	LHV (Btu/lb.)[1]	LHV (Btu/ft^3)[2]
CO_2	44.01	12.0	0	0
N_2	28.016	0.7	0	0
CH_4	16.043	74.6	21,502	880.4
C_2H_6	30.07	6.5	20,416	1566.9
C_3H_8	44.097	3.4	19,929	2243.0
IC_4H_{10}	58.124	0.6	19,614	2909.8
NC_4H_{10}	58.124	1.1	19,665	2917.3
IC_5H_{12}	72.151	0.3	19,451	3582.0
NC_5H_{12}	72.151	0.4	19,499	3590.8
C_6H_{14}	86.178	0.4	19,391	4265.1

$$\begin{aligned}\text{LHV of fuel} &= (.746 \times 880.4) + (.065 \times 1566.9) + (.034 \times 2243.0)\\ &\quad + (.006 \times 2909.8) + (.011 \times 2917.3) + (.003 \times 3582.0)\\ &\quad + (.004 \times 3590.8) + (.004 \times 4265.1)\\ &= 926.6 \text{ Btu/ft}^3 \text{ fuel}\end{aligned}$$

$$V = \frac{nRT}{P} = \frac{(1 \text{ lb. mole})\ (1.314 \text{ atm. ft}^3/\text{lb. mole °K})\ (298.16\text{°K})}{1 \text{ atm.}}$$

$$V = 391.8 \text{ ft}^3/\text{lb. mole}$$

[1]Lower Heating Value from Perry's Chemical Engineers Handbook, 5th Edition, table 3-203.

[2]At 25°C

Now, looking at the combustion calculations for the fuel we get:

.746		1.492		.746		1.492 ← (moles)
CH_4	+	$2O_2$	→	CO_2	+	$2\ H_2O$
.065		.228		.13		.195
C_2H_6	+	$3.5O_2$	→	$2\ CO_2$	+	$3\ H_2O$
.034		.170		.102		.136
C_3H_8	+	$5O_2$	→	$3\ CO_2$	+	$4\ H_2O$
.017		.111		.068		.085
C_4H_{10}	+	$6.5O_2$	→	$4\ CO_2$	+	$5\ H_2O$
.007		.056		.035		.042
C_5H_{12}	+	$8O_2$	→	$5\ CO_2$	+	$6\ H_2O$
.004		.038		.024		.028
C_6H_{14}	+	$9.5O_2$	→	$6\ CO_2$	+	$7\ H_2O$
.873		2.095		1.105		1.978 ← (mole totals)

From this we get:

O_2 needed = 2.095 moles/mole fuel

$N_2 = \frac{79}{21} \times 2.095 = 7.8812$ moles/mole fuel (air is 79% N_2, 21% O_2 by volume)

CO_2 formed = 1.105 moles/mole fuel

H_2O formed = 1.978 moles/mole fuel

So with complete combustion at 0% excess O_2 the flue gas products are:

Component	mole/mole fuel	Stoichiometric flue gas, moles
CO_2	.12 (from fuel) + 1.105 =	1.225
N_2	.007 (from fuel) + 7.8812 =	7.8882
H_2O	1.978	1.978

With complete combustion and 15 percent excess O_2 in the flue gas, the total lb moles O_2 (dry) per lb mole of fuel, X, is calculated by the following equation:

$$\frac{X \text{ lb moles } O_2}{X \text{ moles } O_2 + 1.225 \text{ lb moles } CO_2 + (7.8882 + \frac{79}{21} X) \text{ lb moles } N_2} = .15$$

$$\frac{X}{9.1132 + 4.7619X} = .15$$

$$X = 4.7847 \frac{\text{lb. moles } O_2}{\text{lb. mole fuel}}$$

Therefore, the flue products (dry) are

Component	lb moles/lb mole fuel
CO_2	1.225*
N_2	25.8878
O_2	4.7845
Total (dry)	31.8973

*Note, we ignore 0.03 percent CO_2 in the air.

FUEL RATES AND FLUE GAS RATES FOR EXAMPLE GAS TURBINES

Example Turbine (for calculations)	Rated hp.	Heat Rate (Btu/hp-hr)	lb moles* Fuel/hp-hr	lb moles** Flue (dry)/hp-hr
Solar Saturn T-1001	1,050	12,348	.034013	1.08492
Ingersoll-Rand GT-22	4,250	9,430	.025975	0.82853
Ingersoll-Rand GT-52	15,900	9,365	.025796	0.82282
General Electric M5251	25,000	9,640	.026553	0.84697
General Electric M5262A	26,250	9.780	.026939	0.85928
General Electric M5332B	33,550	8,910	.024542	0.78282

$$\text{*lb moles fuel/hp-hr} = \frac{\text{Heat Rate (Btu/hp-hr)} \times \text{ft}^3 \text{ fuel}}{926.6 \text{ Btu}} \times \frac{\text{lb mole fuel}}{391.8 \text{ ft}^3 \text{ fuel}}$$

$$\text{** lb moles flue (dry)/hp-hr} = \frac{\text{lb moles flue(dry)}}{\text{lb mole fuel}} \times \frac{\text{lb moles fuel}}{\text{hp-hr}} = 31.8973 \times \frac{\text{lb moles fuel}}{\text{hp-hr}}$$

NO_2 Emissions from Gas Turbines

NO_x flue gas concentration = 150 ppmv NO_2 in flue gas on a dry basis at 15 percent excess O_2.

$$NO_x \text{ emissions} \left(\frac{\text{lb}}{1000 \text{ hp-hr}}\right) = \frac{\text{lb moles flue (dry)}}{\text{hp-hr}} \times \frac{.000150 \text{ lb moles } NO_2}{\text{lb mole flue}} \times \frac{46.008 \text{ lb } NO_2}{\text{lb mole}} \times 1000$$

Example Turbine Rate (Hp)	NO_x Emission Factor (lb NO_x/1000 hp-hr)
1,050	7.49
4,250	5.72
15,900	5.68
25,000	5.85
26,250	5.93
33,550	5.40

The NO_x emissions for all ratings of combustion turbines proposed in this permit application were calculated based on a single emission factor (lb NO_x/1000 hp-hr). The factor of 5.9 lb/1000 hp-hr was selected as conservative. The higher number in the table above (7.49 lb/1000 hp-hr for the 1050 HP turbine) was not selected because it was significantly higher than the other values and because it was developed for an example turbine with a rating much lower than most of those proposed in this application.

HC Emissions from Gas Turbines*

Emission factor = 0.2 lb HC/1000 hp·hr from AP-42 p. 149 table 3.3.2-1

$$\text{Proposed turbine h.p.} \times \frac{0.2 \text{ lb HC}}{1000 \text{ hp}\cdot\text{hr}} \times \frac{8760 \text{ hr}}{\text{yr.}} \times \frac{\text{ton}}{2000 \text{ lb}} = \frac{\text{tons HC}}{\text{yr.}}$$

Proposed Turbine, h.p.	Tons HC/yr.
1,400	1.2
3,500	3.1
5,000	4.4
22,000	19.8
25,000	21.9
26,000	23.3
36,000	31.5

*Expressed as total hydrocarbons

CO Emissions from Gas Turbines

Emission factor = 1.1 lb CO/1000 hp·hr from AP-42 p. 149
table 3.3.2-1

$$\text{Proposed turbine h.p.} \times \frac{1.1 \text{ lb CO}}{1000 \text{ hp}\cdot\text{hr}} \times \frac{8760 \text{ hr}}{\text{yr.}} \times \frac{\text{ton}}{2000 \text{ lb}} = \frac{\text{tons CO}}{\text{yr.}}$$

Proposed Turbine, h.p.	Tons CO/yr.
1,400	6.75
3,500	16.86
5,000	24.09
22,600	108.89
25,000	120.45
26,600	128.16
36,000	173.45

Particulate Emissions from Gas Turbines

Potential Emissions:

Emission factor = 14 lb./10^6 ft^3 gas burned, from AP-42, p. 146, table 3.3.1-2.

$$\text{Fuel rate, } \frac{\text{moles fuel}}{\text{hr}} \times \frac{391.8\ \text{ft}^3\ \text{fuel}}{\text{mole fuel}} \times \frac{14\ \text{lb. particulate}}{10^6\ \text{ft}^3\ \text{fuel}} \times \frac{8760\ \text{hr.}}{\text{yr.}} \times \frac{\text{ton}}{2000\ \text{lb.}} = \frac{\text{tons particulate}}{\text{yr.}}$$

Allowable Emissions:

Emission factor = 0.05 grains particulate/ft^3 exhaust at 70°F dry basis.

$$\text{Fuel rate, } \frac{\text{moles fuel}}{\text{hr}} \times \frac{9.11\ \text{moles dry flue}^{[1]}}{\text{moles fuel}} \times \frac{386.7\ \text{ft}^3\ @\ 70^\circ\text{F}^{[2]}}{\text{mole flue}} \times \frac{0.05\ \text{grains}}{\text{ft}^3\ \text{flue gas}} \times$$

$$\frac{\text{lb.}}{7000\ \text{grains}} \times \frac{8760\ \text{hr.}}{\text{yr.}} \times \frac{\text{ton}}{2000\ \text{lb.}} = \frac{\text{tons particulate}}{\text{yr.}}$$

Proposed Turbine, h.p.	Fuel Rate, moles fuel/hr.	Potential Tons Particulate/yr.	Allowable Tons Particulate/yr.
1,400	47.6	1.1	5.2
3,500	90.9	2.2	10.0
5,000	129.9	3.1	14.4
22,000	600.1	14.4	66.1
25,000	663.8	15.9	73.2
26,600	716.6	17.2	79.0
36,000	883.5	21.2	97.4

[1]Value at 0% excess O_2

$$^{2}V = \frac{nRT}{P} = \frac{(1\ \text{lb. mole})\ (1.314\ \text{atm. ft}^3/\text{lb. mole}\ ^\circ\text{K})\ (294.27\ ^\circ\text{K})}{1\ \text{atm.}} = 386.7\ \text{ft}^3/\text{lb. mole}$$

SO_2 Emissions from Gas Turbines

Potential Emissions:

Emission factor = 0.004 lb SO_2/1000 hp-hr from AP-42, p. 149 table 3.3.2-1

$$\text{Proposed turbine hp} \times \frac{0.004 \text{ lb } SO_2}{1000 \text{ hp-hr}} \times \frac{8760 \text{ hr}}{\text{yr}} \times \frac{\text{ton}}{2000 \text{ lb}} = \frac{\text{tons } SO_2}{\text{yr}}$$

Allowable emissions = 150 ppmv SO_2 in flue gas at 15 percent excess O_2, dry basis, 25°C.

Using the same methodology as that used in calculating NO_x emissions:

$$\text{Allowable } SO_2 \text{ emissions } \frac{\text{lb}}{1000 \text{ hp-hr}} = \frac{\text{lb moles flue(dry)}}{\text{hp-hr}} \times$$

$$\frac{.000150 \text{ lb moles } SO_2}{\text{lb mole flue}} \times \frac{64.06 \text{ lb } SO_2}{\text{lb mole}} \times 1000$$

Example Turbine Rate (hp)	SO_2 Emission Factor (Allowable) (lb SO_2/1000 hp-hr)
1,050	10.4250
4,250	7.9613
15,900	7.9065
25,000	8.1385
26,250	8.2568
33,550	7.5221

The allowable SO_2 emissions for all ratings of combustion turbines proposed in this permit application were calculated based on a single emission factor (lb SO_2/1000 hp-hr). The factor of 8.3 lb/1000 hp-hr was selected as conservative. The higher number in the table above (10.4250 lb/1000 hp-hr for the 1050 HP turbine) was not selected because it was significantly higher than the other values and because it was developed for an example turbine with a rating much lower than those proposed in this application.

The potential emissions of pollutants from gas heaters were calculated using the following equation:

$$\text{Annual emission rate, } \frac{\text{tons pollutant}}{\text{yr.}} = \text{Heat rate of heater} \times$$

$$\frac{\text{ft}^3 \text{ fuel}}{926.6 \text{ BTU}} \times \frac{8760 \text{ hr.}}{\text{yr.}} \times \text{emission factor}, \frac{\text{lb. pollutant}}{1{,}000{,}000 \text{ ft}^3 \text{ fuel burned}}$$

$$\times \frac{\text{ton}}{2000 \text{ lb.}}$$

Emission factors were taken from table 1.4-1 of AP-42. They are:

Particulates = 10 lb./10^6 ft^3 gas burned (av'g of 5-15)

SO_2 = 0.6 lb./10^6 ft^3 gas burned

CO = 17 lb./10^6 ft^3 gas burned

HC (as CH_4) = 3 lb./10^6 ft^3 gas burned

NO_x (as NO_2) = 175 lb./10^6 ft^3 gas burned (av'g of 120-230)

The allowable emissions of particulates from gas heaters were calculated using the following equation:

$$\text{Allowable tons particulates/yr} = \text{Heat rate of heater}, \frac{\text{ft}^3 \text{ fuel}}{926.6 \text{ BTU}} \times$$

$$\frac{\text{mole fuel}}{386.6 \text{ ft}^3 \text{ fuel}} \times \frac{9.11 \text{ mole flue}}{\text{mole fuel}} \times \frac{386.6 \text{ ft}^3 \text{ flue}}{\text{mole flue}} \times$$

$$\frac{0.05 \text{ grains}}{\text{ft}^3 \text{ flue}} \times \frac{\text{lb.}}{7000 \text{ grains}} \times \frac{8760 \text{ hr.}}{\text{yr.}} \times \frac{\text{ton}}{2000 \text{ lb.}}$$

The allowable emissions of SO_2 from gas heaters were calculated using the following equation:

$$\text{Allowable tons } SO_2/\text{yr} = \text{Heat rate of heater, } \frac{\text{BTU}}{\text{hr}} \times \frac{\text{ft}^3 \text{ fuel}}{926.6 \text{ BTU}} \times$$

$$\frac{\text{mole fuel}}{386.6 \text{ ft}^3 \text{ fuel}} \times \frac{9.11 \text{ mole flue}}{\text{mole fuel}} \times \frac{386.6 \text{ ft}^3 \text{ flue}}{\text{mole flue}} \times \frac{0.000500 \text{ ft}^3\ SO_2}{\text{ft}^3 \text{ flue}} \times$$

$$\frac{\text{mole } SO_2}{386.6 \text{ ft}^3\ SO_2} \times \frac{64.066 \text{ lb } SO_2}{\text{mole } SO_2} \times \frac{8760 \text{ hr.}}{\text{yr.}} \times \frac{\text{ton}}{2000 \text{ lb.}}$$

EMISSIONS FROM FUEL OIL STORAGE TANKS

Estimated Emissions Losses Per Tank

1. Breathing Losses

$$L_B = 2.21 \times 10^{-4} M \left(\frac{P}{14.7-P}\right)^{0.68} D^{1.73} H^{0.51} \Delta T^{0.50} F_p C K_c$$

Where

L_B = Breathing losses, #/day

M = Mole wt = 130 #/# mole (Table 4.3-1, AP-42) (Conservatively assumed jet kerosene)

P = Vapor pressure = 0.0041 psia (Table 4.3-1, AP-42)

D = Tank diameter = 25 feet (typical)

H = Average vapor space height = 12 feet

ΔT = Daily temperature change = 20°F

F_p = Paint factor = 1.39 for aluminum (Table 4.3-2, AP-42)

C = Adjustment factor for small tanks = 0.97 (Figure 4.3-10, AP-42)

K_c = Crude oil factor = 1 (AP-42, page 43.6)

Therefore L_B = .617 #/day per tank

2. Working losses

$$L_w = 2.40 \times 10^{-2} M P K_n K_c$$

Where

L_w = Working losses, #/1000 gal throughput

M = Mole wt = 130 #/# mole (Table 4.3-1, AP-42)

P = Vapor pressure = .0041 psia (Table 4.3-1, AP-42)

K_{N^2} = Turnover factor = 1.0 (Figure 4.3-11, AP-42)

K_c = Crude oil factor = 1.0 (non-crude oil)

Therefore L_W = 0.01279 #/1000 gal throughput and working

losses = (0.01279 #/1000 gal)(42,000 gal/yr)*

= 0.5 #/yr per tank

Estimated Total Losses for three tanks

Losses = 3 (Breathing losses + Working losses)

Losses = 3 [(.617 #/day)(365 day/yr) + 0.5 #/yr]

= 3 (225.3 #/yr + 0.5 #/yr)

= 677 #/yr

= 0.34 Ton/yr.

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*Assumed since fuel oil will be used only in emergencies.

NOTE: The tank dimensions assumed are typical and conservative. Actual tankage may have a smaller diameter.

APPENDIX C

EMISSIONS INVENTORY

TABLE C-1

EXISTING NON-INCREMENT CONSUMING SOURCES

MAP ID	SOURCE ID	UTM EAST	UTM NORTH	NO_x	SO_2	PART.		CO		HS	TS	DS	VS
				Annual g/s	Short Term g/s	Short Term g/s	Annual g/s	Short Term g/s	Short term g/s	(m)	(°K)	(m)	(m/sec)
*	ARCO P-357	449.5	7794.6	0.434	.001	.019	0.0190	.032	.006	15.2	623.	1.	10.6
*	ARCO P-357	449.5	7794.6	0.03	.001	.003	0.0030	.004	.001	15.2	623.	.3	10.6
ACC	ARCO P-358	448.4	7794.7	2.7	.007	.117	0.1170	.198	.035	15.2	623.	1.	10.6
ACT	ARCO P-136	449.3	7794.4	1.33	.00	.116	0.1160	.00	.17	15.2	555.	1.2	10.6
ACT	ARCO P-136	449.3	7794.4	0.04	.113	.038	0.0380	.94	.706	10.7	1033.	.9	6.9
FS-1	ARCO P-138	446.	7795.2	14.8	.021	.502	0.5020	4.12	1.5	13.1	644.	2.5	20.1
FS-1	ARCO P-138	446.	7795.2	2.98	.00	.025	0.0250	.00	.38	15.2	623.	.3	10.6
FS-2	ARCO P-381	449.5	7795.5	14.8	.021	.502	0.5020	4.12	1.5	13.1	644.	2.5	20.1
FS-2	ARCO P-381	449.5	7795.5	2.98	.00	.025	0.0250	.00	.38	15.2	623.	.3	10.6
FS-3	ARCO P-443	440.7	7795.7	14.8	.021	.502	0.5020	4.12	1.5	13.1	644.	2.5	20.1
FS-3	ARCO P-443	440.7	7795.7	2.98	.00	.025	0.0250	.00	.38	15.2	623.	.3	10.6
AFG	ARCO P-326	443.7	7802.2	0.578	.00	.5	0.5000	.00	.075	16.1	611.	.9	10.6
*	ARCO P-324	443.7	7802.2	164.	.239	5.58	5.5800	45.70	16.7	26.8	755.	2.4	50.6
*	ARCO P-324	443.7	7802.2	1.53	.004	.066	0.0660	.113	.02	9.1	519.	1.1	10.6
CC-1	SOHIO P-338	435.8	7799.5	0.037	.063	.176	0.095	.25	.076	7.3	1088.	.5	6.9
CC-1	SOHIO P-338	435.8	7799.5	0.13	.064	.16	0.086	.009	.032	7.3	1088.	.5	7.4
CPS	SOHIO P-185	437.5	7797.2	109.2	.158	3.7	3.7000	30.30	11.4	15.8	777.	2.7	50.6
CPS	SOHIO P-185	437.5	7797.2	20.31	.029	.69	0.6900	5.63	2.12	15.8	777.	2.7	50.6
DW	DOW. P-325	447.9	7792.	1.25	.059	.044	0.0440	..767	.125	3.7	721.	.2	15.2
DW	DOW. P-325	447.9	7792.	0.078	.16	.067	0.0670	.006	.004	3.7	721.	.2	7.4
N1	NANA P-413	447.3	7791.	0.76	.63	.011	0.0110	8 82	.377	20.	450.	.9	13.7
N1	NANA P-413	447.3	7791.	.38	.32	.006	0 .006	4.41	.189	20.	450.	.9	7.4
*	ALY. P-289	439.	7796.	25.1	.036	.85	0.6500	6.99	2.55	13.7	727.	3.3	22.8
*	ALY. P-289	439.	7796.	1.04	.001	.035	0.0350	.289	.105	13.7	727.	3.3	22.8
*	ALY. P-289	439.	7796.	1.56	.004	.067	0.0670	.115	.02	13.7	623.	1.	10.7
*	ALY. P-289	439.	7796.	0.0	.014	.001	0.0010	.00	0.0	7.9	1144.	.4	6.9
*	ALY. P-289	439.	7796.	0.062	.01	.003	0.0030	.001	.002	7.9	1144.	.4	7.4
N2	NANA P-423	444.4	7789.4	9.66	.64	.69	0.6900	2.09	.77	7.6	421.	.5	18.3
N2	NANA P-434	444.4	7789.4	.04	.113	.707	.707	.904	0.706	10.7	1032.	.9	6.9
VE	VE P-482	446.	7791.6	7.00	.47	.5	0.39	1.51	.56	7.6	421.	.5	15.2
VE	VE P-482	446.	7791.6	0.195	.055	.35	0.3500	.47	.35	10.6	1033.	.9	6.9
*	ARCO OPS CR	449.8	7794.6	0.26	.431	.047	0.0350	.153	.397	12.2	971.	1.1	6.9
*	ARCO OPS CR	449.8	7794.6	0.08	.038	.018	0.0140	.01	.042	12.2	1366.	.8	7.4
*	SOHIO BOC	435.8	7799.5	0.063	.034	.02	0.0200	.007	.008	12.2	1366.	.5	6.9
*	SOHIO BOC	435.8	7799.5	0.003	.052	.002	0.00	.13	.404	12.2	1088.	.5	7.4
*	SOHIO BOC	435.8	7799.5	.2	.53	.4	0.009	6.91	1.14	6.7	660.	.5	18.3
CC-2	SOHIO P-374	430.	7803.5	0.03	.047	.066	0.0660	.187	.056	12.2	1088.	.5	6.9
CC-2	SOHIO P-374	430.	7803.5	0.106	.054	.041	0.0410	.009	.022	12.2	1088.	.5	7.4
*	DH. ARPRT	445.	7789.	15.67	1.14	1.12	1.1200	3.38	1.25	10.7	428.	.6	22.8
FC	FRONTIER	445.7	7791.2	7.83	.52	.56	0.5600	1.69	.63	10.7	428.	.5	18.3
*	AGC	427.	7801.8	2.61	.17	.19	0.1900	.56	.21	10.7	428.	.3	18.3
	Downtown	446.5	7791.2	13.06	.87	.93	0.9300	2.82	1.04	10.7	428.	.6	15.2
GC-1	SOHIO GC1	434.7	7801.	2.83	.009	.121	0.1210	.20	.04	10.	506.	.61	14.2
GC-1	SOHIO GC1	434.7	7801.	0.38	.0009	.02	0.0200	.02	.004	18.	506.	.41	8.6
GC-2	SOHIO GC2	430.	7801.8	2.83	.009	.121	0.1210	.20	.04	10.	506.	.61	14.2
GC-2	SOHIO GC2	430.	7801.8	0.38	.0009	.02	0.0200	.02	.004	18.	506.	.41	8.6
GC-3	SOHIO GC3	436.7	7798.5	2.83	.009	.121	0.1210	.20	.04	10.	506.	.61	14.2
GC-3	SOHIO GC3	436.7	7798.5	0.38	.0009	.02	0.0200	.02	.004	18.	506.	.41	8.6
CPS	SOHIO CPS	437.5	7797.2	0.28	.0009	.012	0.0120	.02	.004	18.	506.	.38	3.5

TABLE C-2

INCREMENT CONSUMING SOURCES IN THE UNIT OPERATORS' 1978 PSD APPLICATION

MAP ID	UTM EAST	UTM NORTH	NO_x Annual g/s	SO_2 Short Term g/s	PART. Short Term g/s	PART. Annual g/s	CO Short Term g/s	NMHC Short Term g/s	HS (m)	TS (°K)	DS (m)	VS (m/sec)
ARCO CCP	443.7	7802.2	41.19	.06	1.395	1.3950	11.45	4.19	26.8	755.	2.43	50.6
ARCO FS-2	449.5	7795.5	27.18	.04	.92	0.9200	7.54	2.76	26.8	755.	2.43	50.6
SOHIO CPP	437.5	7797.2	74.16	.106	2.51	2.5100	20.62	7.53	16.7	755.	2.8	42.
SOHIO GC2	430.	7801.8	35.33	.052	1.2	1.2000	9.80	3.58	16.7	755.	2.69	60.
SOHIO GC3	436.7	7798.5	17.66	.029	.6	0.6000	4.90	1.79	16.7	755.	2.69	35.

TABLE C-3

PROPOSED NEW SOURCES*

MAP ID	UTM East	UTM North	NO_x Annual (g/s)	SO_2 (g/s)	Part Short-term (g/s)	Part Annual (g/s)	CO (g/s)	NMHC (g/s)	HS (m)	TS (°K)	DS (m)	VS (m/s)
GC-1	434.7	7801.	5.20	.003	.115	0.1150	.95	.17	16.7	830.	.88	50.
GC-1	434.7	7801.	1.04	.0006	.03	0.0300	.20	.03	16.7	830.	.55	50.
GC-1	434.7	7801.	67.20	.046	1.67	1.6700	12.54	2.27	16.7	830.	2.23	50.
GC-1	434.7	7801.	2.04	.007	.115	0.1150	.20	.03	18.3	623.	1.26	10.6
GC-1	434.7	7801.	0.12	.0003	.007	0.0070	.012	.002	18.3	623.	.43	10.6
GC-1	434.7	7801.	7.39	.025	.42	0.4200	.72	.127	18.3	623.	3.41	10.6
GC-2	430.	7801.8	5.20	.003	.115	0.1150	.95	.17	16.7	830.	.88	50.
GC-2	430.	7801.8	1.04	.0006	.03	0.0300	.20	.03	16.7	830.	.55	50.
GC-2	430.	7801.8	67.20	.046	1.67	1.6700	12.54	2.27	16.7	830.	2.23	50.
GC-2	430.	7801.8	59.32	.155	1.5	1.5000	11.04	2.01	16.7	830.	2.41	50.
GC-2	430.	7801.8	3.05	.01	.17	0.1700	.29	.05	18.3	623.	1.26	10.6
GC-2	430.	7801.8	7.39	.025	.42	0.4200	.72	.127	18.3	623.	3.41	10.6
GC-2	430.	7801.8	0.12	.0003	.007	0.0070	.012	.002	18.3	623.	.43	10.6
GC-3	436.7	7798.5	5.20	.003	.12	0.1200	.95	.17	16.7	830.	.88	50.
GC-3	436.7	7798.5	1.04	.0006	.03	0.0300	.20	.03	16.7	830.	.55	50.
GC-3	436.7	7798.5	67.20	.046	1.67	1.6700	12.54	2.27	16.7	830.	2.23	50.
GC-3	436.7	7798.5	2.01	.007	.115	.115	.20	.03	18.3	623.	1.26	10.6
GC-3	436.7	7798.5	0.12	.0003	.007	0.0070	.012	.002	18.3	623.	.43	10.6
GC-3	436.7	7798.5	7.39	.025	.42	0.4200	.72	.127	18.3	623.	3.41	10.6
DRILL PAD E	437.1	7804.7	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD F	433.5	7804.4	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD G	435.0	7802.3	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD D	434.9	7799.6	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD H	430.9	7800.1	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD J	430.9	7803.2	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD M	426.4	7804.2	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD N	428.1	7802.5	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD R	428.5	7804.2	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD Q	431.	7801.6	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD S	423.5	7804.2	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD Y	431.2	7796.8	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD A	434.	7796.6	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD C	437.3	7799.7	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD X	437.0	7793.3	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
DRILL PAD B	437.	7796.6	0.24	.0009	.014	0.0140	.023	.004	14.	506.	.6	14.3
CCP	443.7	7802.2	18.58	.013	.46	0.4600	3.45	.63	26.8	768.	2.46	50.
CCP	443.7	7802.2	0.63	.002	.03	0.0300	.06	.01	9.1	519.	.5	14.1
FS-1	446.	7795.2	7.45	.005	.18	0.1800	1.40	.25	16.8	748.	1.	29.7
FS-1	446.	7795.2	80.29	.054	1.84	1.8400	14.96	2.73	26.8	768.	3.	37.6
FS-2	449.5	7795.5	107.05	.072	2.45	2.4500	19.96	3.62	26.8	768.	3.	37.6
FS-2	449.5	7795.5	7.45	.005	.18	0.1800	1.40	.25	16.8	748.	1.	29.7
FS-2	449.5	7795.5	2.39	.009	.14	0.1400	.23	.04	18.3	623.	1.94	10.6
FS-3	440.7	7795.7	107.05	.072	2.45	2.4500	19.96	3.62	26.8	768.	3.	37.6
FS-3	440.7	7795.7	7.45	.005	.18	0.1800	1.40	.25	16.8	748.	1.	29.7

APPENDIX D

DISPERSION MODELING TECHNIQUES

APPENDIX D

Steady-state Gaussian dispersion models developed by the Environmental Protection Agency and applicable for flat terrain conditions were employed in the air quality impact analyses of this study. In the application of all models, an infinite half-life for all pollutants was assumed. In addition, it was assumed that all oxides of nitrogen were emitted as NO_2. The plume rise algorithms of three of the models used (TCM, CRSTER, and RAM) were modified to treat turbine plume rise during stable and neutral conditions, and the RAM model was altered to account for the effects of building-induced wake downwash of plumes. The CRSTER preprocessor mixing height and sunrise/sunset algorithms were also modified. All basic models used in this study are included in the list of EPA-recommended models found in the EPA Guidelines on Air Quality Models (EPA, 1978).

Texas Climatological Model (TCM)

All annual modeling was performed using the Texas Climatological Model (TCM). The TCM is a climatological model that predicts long-term arithmetic mean concentrations of non-reactive pollutants from point and area sources (Christiansen and Porter, 1976).

The TCM uses meteorological data in the form of a 576-entry meteorological joint frequency function of wind speed, wind direction and stability class. It uses the Gaussian plume hypothesis for dealing with elevated point sources. Briggs' plume rise formulas and exponential pollutant decay are incorporated in the model.

The following types of data are input into the TCM. The first type is the control parameters including grid size, location, and spacing, mean ambient temperature, decay half-lives of the pollutants, and output options. The second type of data is the meteorological data. A meteorological joint frequency distribution of wind speed, wind direction, and stability class is input from cards or disk file storage. The third type of data is the point source data file including source location, stack diameter and height, exit gas temperature and velocity, and pollutant emission rate.

TCM output includes a listing of all point source input data plus a rectangular array of predicted concentrations, in micrograms per cubic meter ($\mu g/m^3$). Optional output includes a listing of each receptor in the grid with the calculated concentration in $\mu g/m^3$. A culpability option can be specified. This produces a listing of the five highest contributors to the concentration (by percent concentration) at each grid point.

Although very similar to the EPA-developed Climatological Dispersion Model (CDM) (Busse and Zimmerman, 1973), the TEC as applied to point sources differs from the CDM in several areas. In the development of the TCM, a separate program was run which solved the Gaussian plume equation for many combinations of effective source height and downwind distance in each stability class. The results are incorporated into the TCM as a table of coefficients. For each source-receptor configuration, the TCM interpolates in the table instead of solving the Gaussian plume equation explicitly.

Another difference between the models is that with the TCM and average wind speed independent of wind direction is calculated for each stability class. Within a stability class, the spread in wind speed is typically small, and wind speed is a weak function of wind direction, so the simplification seems justified.

Also the TCM allows for the use of stable Pasquill-Gifford dispersion coefficients during periods identified as stable (E+F) by the meteorological joint frequency function. This differs from the CDM, an urban model, which uses the neutral Pasquill-Gifford dispersion coefficients for both neutral (D day and D night) and stable (E+F) conditions to account for the absence of stable conditions in the nightime urban boundary layer. For this reason, the TCM, rather than the CDM was selected for use in modeling sources at Prudhoe Bay, an essentially rural area.

Modifications to the plume rise calculation algorithm in TCM, made especially for this study are discussed in a later section of this appendix.

PTMAX

The EPA-developed PTMAX model was used to perform an initial screening analysis of CO emissions to determine if additional short-term dispersion modeling analyses were required for this pollutant. PTMAX is a short-term Gaussian model designed to predict maximum concentrations as a function of wind speed and stability for point sources located in flat terrain areas.

A separate analysis is made for each individual stack. Input to the program consists of ambient air temperature, and characteristics of the source, such as emission rate, physical stack height, and stack gas temperature. Either the stack gas volume flow or both the stack gas velocity and inside diameter at the top are also required. Outputs of the program consist of effective height of emission, maximum ground level concentration, and distance of maximum concentration for each condition of stability and wind speed.

PTMAX determines for each wind speed and stability the final plume rise using methods suggested by Briggs. This plume rise is added to the physical stack height to determine the effective height of emission. The effective height is used to determine both the maximum concentration and the distance to maximum concentration. The Pasquill-Gifford horizontal and vertical dispersion coefficients are incorporated into the model.

CRSTER

The EPA Single-Source (CRSTER) Model was used to perform initial short-term (3 hour and 24 hour) dispersion analyses for emissions of particulates and hydrocarbons. The results of these analyses were used in selecting worst-case dispersion conditions to be examined in more detailed multi-source dispersion analyses.

CRSTER can examine the impact of up to 19 stacks collocated at a single point for averaging periods ranging from 1-hour to 24-hours. The model is applicable to both urban and rural conditions as well as for flat or uneven terrain. Maximum and second highest concentrations for different downwind directions and different radial distances from the collocated sources are displayed in the CRSTER output. The dates and hours of occurrences of these maximum concentrations are also presented. Because of these output features as well as the relatively low cost associated with examining long periods of meteorological data (1 year in this study) CRSTER was selected for initial short-term modeling.

Briggs' final plume rise formulas (Briggs, 1969) and Pasquill-Gifford dispersion coefficients as reported by Turner are incorporated into the model. Meteorological inputs to CRSTER consist of hourly values of wind speed, wind direction, mixing height and stability class, prepared by a special pre-processor program. This program requires as input hourly surface meteorological observations and twice-daily mixing heights available from the National Climatic Center. Other inputs to CRSTER include pollutant emission rates (for a single pollutant only), stack height and diameter, stack exit velocity and temperature and 5 receptor ring distances (EPA, 1977).

Modifications to the plume rise calculation algorithms in CRSTER and modifications to the mixing depth and sunrise/sunset algorithms in the CRSTER preprocessor were made especially for this study. These changes are discussed in a later section of this appendix and in Appendix E.

RAM

The EPA RAM model was used to perform detailed short-term dispersion analyses for emissions of particulates and hydrocarbons. 3-hour and 24-hour meteorological conditions identified as potentially worst-case from the CRSTER outputs were input to RAM to determine impacts on the short-term NAAQS.

In addition, RAM was modified to predict the effects of building wake downwash of plumes from non-collocated sources. RAM is a multiple source model capable of predicting maximum impacts within a honeycomb receptor grid for flat terrain or gently rolling terrain and for rural or urban conditions. Because of its capability to predict maximum interactive impacts resulting from multiple, non-collocated source emissions, the

RAM (rural) model was selected for detailed short-term analyses in this study.

RAM accepts the same meteorological inputs as CRSTER. However, for this study, several individual 3-hour and 24-hour periods, as opposed to a complete year or more of data, were input to RAM. Emissions and stack parameters required by RAM are identical to those input to CRSTER.

Briggs' initial and final plume rise formulas are incorporated into RAM. In addition the RAM plume rise formulas account for the phenomenon of stack downwash, a feature not included in CRSTER. Pasquill-Gifford dispersion coefficients as reported by Turner are used in the rural version of RAM (Turner and Novak, 1978).

Modification of Plume Rise Calculations for Gas Turbines

EPA Region X has recommended that the standard plume rise calculated by the Briggs' Formulation (Briggs, 1969) be modified for predicting plume rise by gas turbines. This recommendation is based primarily upon a journal article by England et al., (England, 1976) describing a series of measurements of the plume rise from a single gas turbine facility. Region X recommends that gas turbine exhaust plume rise is best described by using 7/10 of the value predicted by Briggs' formula for unstable and neutral atmospheric conditions.

In accordance with this recommendation, Radian modified the plume rise algorithms in the RAM, CRSTER, and TCM dispersion models. Those modifications resulted in 7/10 Briggs' plume rise being calculated when determining the plume rise from the proposed gas turbines. Listings of the FORTRAN code for the modifications to RAM, CRSTER, and TCM are given in Tables D-1, D-2, and D-3, respectively, included at the end of this section. The new or changed lines of code are identified in these tables.

The 7/10 Briggs' plume rise approach is often supported by those who favor its use based on the following information:

- The research by England et al., directly measured the plume rise for a gas turbine facility. Briggs' method, however, is based upon data from numerous different types of sources. As such, Briggs' method may be the best over all predictor of plume rise, but it is not necessarily the best in every situation. Thus, a source specific method is preferable to a generalized formula applicable over a wide range of source types.

- The use of 7/10 Briggs' plume rise is conservative. The ground level concentration produced by a source is an inverse function of the effective stack height. As a result the lower the effective stack height is, the higher the ground level concentration is, in most situations. Thus, by use of a method predicting lower plume rises, the predicted ground level concentrations are conservative, when compared to those concentrations predicted using full Briggs' plume rise.

There are several important reasons not to use the 7/10 Briggs' plume rise but rather, full Briggs' plume rise.

- The England et al., article describes only a single facility where plume rise was measured in only a limited number of situations. As such, it is difficult to determine whether some unique factor specific to the gas turbine facility tested was responsible for the lower plume rise observed compared to Briggs' plume rise. Additional studies are needed to clarify the effect of source and site-specific factors affecting plume rise from gas turbines.

- The plume rises measured in the study occurred under neutral and stable atmospheric conditions only. Region X recommends using 7/10 Briggs' plume rise for both neutral and unstable conditions. However, plume rise was not observed under unstable conditions. There thus appears to be no justification for using 7/10 Briggs' plume rise for unstable atmospheric conditions. Again, further studies are needed to assess gas turbine plume rise under unstable atmospheric conditions.

- The England paper reported plume rise under stable conditions of almost double that predicted by Briggs' formulas. Region X, though, recommends that Briggs' plume rise be used for stable atmospheric conditions. Even though this is a conservative approach because the lower predicted plume rise is used under stable conditions, it does appear to be contradictory. If one part of the England study is valid, all parts should be equally valid.

- The EPA has issued no official policy statement concerning plume rise from gas turbines. The lack of this policy statement probably shows that there still exists technical debate over plume rise from gas turbines.

Until the time that the EPA does issue a policy statement, the Unit Operators feel that the standardized Briggs' plume rise should be used for gas turbines. However, in the interest of ensuring processing of the PSD application, the Unit Operators agree and used 7/10 Briggs' plume rise when modeling these gas turbines. This in no way implies that the Unit Operators approve or support of this modification to Briggs' plume rise, for use in modeling gas turbines at Prudhoe Bay.

Downwash Analysis Methods

At the request of EPA Region X downwash analyses were performed, although the PSD regulations do not clearly indicate the need for downwash analyses in this study.

The RAM model was modified to include plume downwash caused by turbulence in the wake of nearby buildings. Plume entrainment due to wake turbulence can cause significantly higher ground level concentrations immediately downwind of the buildings than if there were no nearby buildings present.

A mathematical model for predicting the enhanced plume dispersion in a building's wake has been developed by Huber (1979). This technique provides a method for calculating enhanced horizontal and vertical dispersion coefficients which can be incorporated into standard Gaussian disperion models. The technique is based on the following mathematical equations:

$$\sigma_y = 0.7\ H_w/2 + 0.067\ (X-3H_b);\ \text{if}\ 3\ H_b < X < 10\ H_b$$

or

$$= \sigma_y\ (X + S_y);\ \text{if}\ X \geq 10\ H_b$$

and

$$\sigma_Z = 0.7\ H_b + 0.067\ (X-3H_b);\ \text{if}\ 3\ H_b < X < 10\ H_b$$

or

$$= \sigma_Z\ (X + S_Z);\ \text{if}\ X \geq 10\ H_b$$

where:

H_w = width of influential building normal to wind

H_b = height of highest influential building

X = downwind distance from building edge

S_y = the virtual source distance such that: $\sigma_y\ (10\ H_b + S_y) = 0.7\ H_w/2$ to $5\ H_b$

S_Z = the virtual source distance such that: $\sigma_Z\ (10\ H_b + S_Z) = 1.2\ H_b$

σ_y & σ_Z = the values of the horizontal and vertical dispersion parameters in the absence of building influences.

This method only allows concentrations to be calculated at receptors 3 Hb or greater from the building.

Two subprograms of the EPA RAM model were modified and a third was added to accommodate Huber's downwash algorithm. The main program was changed so the building size dimensions, H_b and H_w, could be input. The subroutine PGSYSZ, which calculates σ_y and σ_Z for the rural version of RAM, calls the new subroutine DOWAZY. This new routine calculates the virtual distances S_y and S_Z for the six stability classes. These distances are calculated by using the inverses of the expressions RAM uses to calculate σ_y and σ_Z. The virtual distances are then added to the original distances in PGSYSG to calculate the enhanced dispersion coefficients σ_y and σ_Z.

Simplified flow charts of the algorithm are illustrated in Figures D-1 and D-2. Following these figures are computer listings of SUBROUTINE DOWAZY and modifications to the RAM SUBROUTINE PGSYSZ (Tables D-4 and D-5).

ENTER

↓

SIGMAY = 0.7 Hw/2 + 0.5 H_b

SIGMAY = 1.2 H_b

↓

CHECK STABILITY TO DETERMINE
WHICH SET OF EQUATIONS TO USE
FOR CALCULATING Sy AND Sx

↓

Sy = f (SIGMAY, Stability)

Sx = f (SIGMAZ, Stability)

↓

If Sy > 100; SY = 100

If Sx > 100; Sx = 100

Sy = Sy - 10 H_b

Sx = Sx - 10 H_b

If Sy < 0; Sy = 0

If Sx < 0; Sx = 0

RETURN

Figure D-1. Subroutine DOWAZY

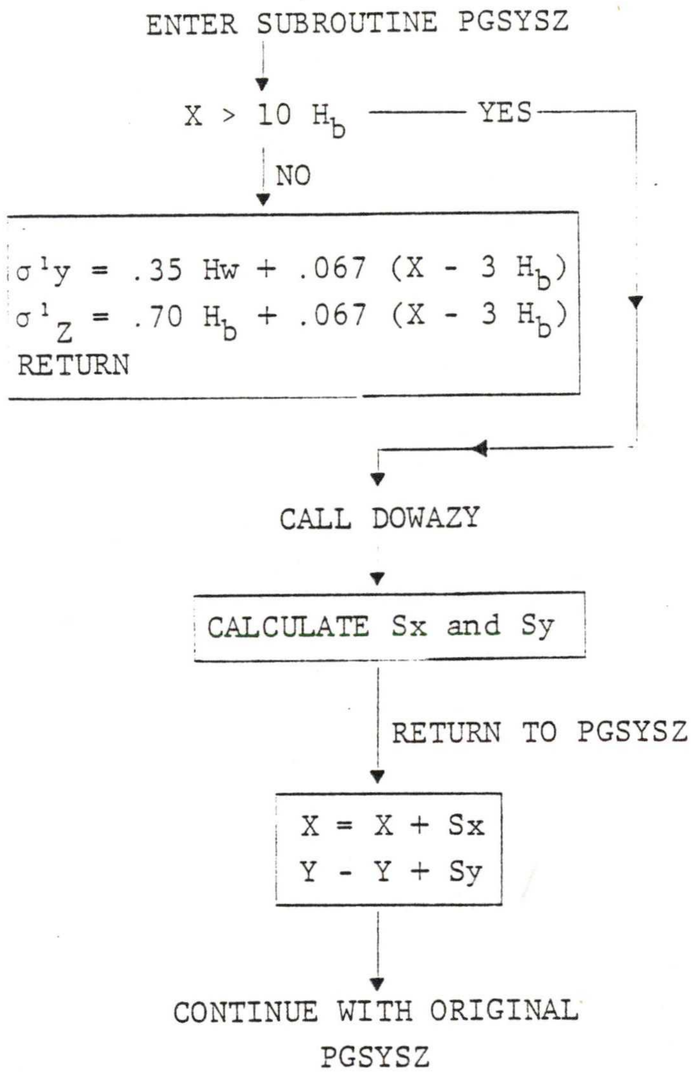

Figure D-2. Modifications to PGSYSZ

TABLE D-1

RAM CODE LISTING - PLUME RISE MODIFICATION

```
0003 I 007344 IOPT      0003 I 007361 IPOL      0004 I 013476 IPSIGS    0003   007367 IRSIZE    0003
0002   000000 ITYPE     0004   014101 IWD       0000 I 001356 J         0000 I 001357 K         0000 I
0004 I 014072 KST       0003   007332 MAS       0003   007301 MPS       0003   007372 NAS       0002
0002   000457 NID       0002 I 000456 NIP       0003 I 007371 NPT       0003 I 007362 NRECEP    0003
0003   007373 NSIGP     0004 R 014102 PARTC     0004 R 000226 PCHI      0004 R 014722 PHCHI     0004 R
0004 R 030026 PL        0003   007375 PNAME     0000 R 001414 PROD      0003 R 010361 PSAV      0004 R
0005   000110 QHL       0005   000140 QTEMP     0005   000000 QTHETA    0005   000030 QU        0003
0003   007363 RMIN      0000 R 001360 RO        0003 R 006625 RREC      0000 R 001406 S         0000 R
0004 R 014075 SINT      0003   007366 SMAX      0003   007365 SMIN      0003 R 001161 SOURCE    0000 R
0003 R 007053 SREC      0000 R 001412 SY        0000 R 001413 SZ        0004 R 014074 TEMP      0000 R
0004   014070 THETA     0000 R 001367 THT       0000 R 001373 TS        0000 R 001415 TT        0004 R
0003   006623 UNITS     0000 R 000000 UPH       0000 R 001370 UPL       0000 R 001371 VS        0000 R
0000 R 001362 XDUM      0000 R 001365 Y         0000 R 001363 YDUM
```

```
00101            SUBROUTINE JMHPTR (HSAV,DSAV,Z,TLOS,LH)                                PTR0010   00000
00101      C      THE PURPOSE OF THIS ROUTINE IS TO CALCULATE CONCENTRATIONS FROM       PTR0020   00000
00101      C      POINT SOURCES.                                                        PTR0030   00000
00101      C      INPUT VARIABLES ARE...                                                PTR0040   00000
00101      C         HSAV- AN ARRAY OF EFFECTIVE HEIGHTS FOR POINT SOURCES(METERS)      PTR0050   00000
00101      C         DSAV-AN ARRAY OF DISTANCES TO FINAL RISE(KM)                       PTR0060   00000
00101      C         Z- RECEPTOR HEIGHT.                                                PTR0070   00000
00101      C         TLOS- PARTITAL COMPUTATION RELATED TO POLLUTANT LOSS.              PTR0080   00000
00101      C         IDATE- YEAR AND JULIAN DAY(IN COMMON/METDAT/)                      PTR0090   00000
00101      C         LH- HOUR                                                           PTR0100   00000
00103            COMMON /SORC/ IA(25,25),SOURCE(9,250),ASORC(6,100),UNITS,CONTWO,RR   PTR0110   00000
00103           1EC(150),SREC(150),MPS(25),MAS(10),IOPT(13),IPOL,NRECEP,RMIN,RMAX,S   PTR0120   00000
00103           2MIN,SMAX,IRSIZE,ISSIZE,NPT,NAS,NSIGP,NSIGA,PNAME(2,250),PSAV(250)    PTR0130   00000
00104            COMMON /METCON/ ACHI(150),PCHI(150),ASIGS(150,11),PSIGS(150,26),IA   PTR0140   00000
00104           1SIGS(100),IPSIGS(250),THETA,U,KST,HL,TEMP,SINT,COST,BPH(2),IWD,PAR   PTR0150   00000
00104           2TC(250),AHCHI(150),PHCHI(150),AHSIGS(150,11),PHSIGS(150,26),PL(6)    PTR0160   00000
00105            COMMON /METDAT/ QTHETA(24),QU(24),IKST(24),QHL(24),QTEMP(24),IDATE   PTR0170   00000
00105           1(2)                                                                  PTR0180   00000
00106            COMMON ITYPE(150),ICODE(150),IN,IO,NIP,NID,NAVG                        PTR0190   00000
00107            DIMENSION HSAV(NPT), DSAV(250), UPH(250), HPR(250), FP(250)           PTR0200   00000
00107      C***                                                                         PTR0210   00000
00107      C***                                                                         PTR0220   00000
00107      C***ZERO EFFECTIVE STACK HEIGHT FOR EACH SOURCE                              PTR0230   00000
00107      C***                                                                         PTR0240   00000
00110            DO 10 J=1,NPT                                                          PTR0250   00000
00113      10    HSAV(J)=0.0                                                            PTR0260   00001
```

TABLE D-1 (Continued)

```
00113   C***LOOP ON RECEPTORS.**                                           PTR0270   00001
00115         DO 120 K=1,NRECEP                                            PTR0280   00001
00115   C***                                                               PTR0290   00001
00115   C***CALCULATE CONCENTRATIONS FROM POINT SOURCES***                 PTR0300   00001
00115   C***       LOOP ON POINT SOURCES                                   PTR0310   00001
00115   C***                                                               PTR0320   00001
00120         DO 110 J=1,NPT                                               PTR0330   00002
00123         PARTC(J)=0.0                                                 PTR0340   00003
00124         RQ=SOURCE(1,J)                                               PTR0350   00003
00125         SQ=SOURCE(2,J)                                               PTR0360   00003
00125   C***DETERMINE UPWIND DISTANCE                                      PTR0370   00003
00125   C***XDUM,YDUM IN INTERNAL UNITS. X,Y IN KM.                        PTR0380   00003
00126         XDUM=RQ-RREC(K)                                              PTR0390   00004
00127         YDUM=SQ-SREC(K)                                              PTR0400   00004
00130         X=(YDUM*COST+XDUM*SINT)*CONTWO                               PTR0410   00004
00130   C*** X IS THE UPWIND DISTANCE  OF THE SOURCE FROM THE RECEPTOR.    PTR0420   00004
00130   C***IF X IS NEGATIVE, INDICATING THAT THE SOURCE IS DOWNWIND OF    PTR0430   00004
00130   C***THE RECEPTOR, THE CALCULATION IS TERMINATED ASSUMING NO        PTR0440   00004
00130   C***CONTRIBUTION FROM THAT SOURCE.                                 PTR0450   00004
00131         IF (X.LE.0.0) GO TO 110                                      PTR0460   00005
00131   C***                                                               PTR0470   00005
00131   C***DETERMINE CROSSWIND DISTANCE                                   PTR0480   00005
00131   C***                                                               PTR0490   00005
00133         Y=(YDUM*SINT-XDUM*COST)*CONTWO                               PTR0500   00005
00134         HF=HSAV(J)                                                   PTR0510   00006
00134   C***SKIP PLUME RISE CALCULATION IF EFFECTIVE HEIGHT HAS ALREADY BEEN  PTR0520   00006
00134   C***    CALCULATED FOR THIS SOURCE                                 PTR0530   00006
00135         IF (HF.GT.0.0) GO TO 80                                      PTR0540   00006
00135   C*** MODIFY WIND SPEED BY POWER LAW PROFILE IN ORDER TO TAKE INTO  PTR0550   00006
00135   C***ACCOUNT THE INCREASE OF WIND SPEED WITH HEIGHT.                PTR0560   00006
00135   C***ASSUME WIND MEASUREMENTS ARE REPRESENTATIVE FOR A 10 METER HEIGHT.  PTR0570   00006
00137         THT=SOURCE(5,J)                                              PTR0580   00006
00137   C***POINT SOURCE HEIGHT NOT ALLOWED TO BE LESS THAN 1 METER.       PTR0590   00006
00140         IF (THT.LT.1.) THT=1.                                        PTR0600   00007
00142         UPL=U*(THT/10.)**PL(KST)                                     PTR0610   00007
00142   C***WIND SPEED NOT ALLOWED TO BE LESS THAN 1 METER/SEC.            PTR0620   00007
00143         IF (UPL.LT.1.) UPL=1.                                        PTR0630   00011
00145         UPH(J)=UPL                                                   PTR0640   00012
00146         VS=SOURCE(8,J)                                               PTR0650   00012
00147         BUOY=SOURCE(9,J)                                             PTR0660   00012
00150         TS=SOURCE(6,J)                                               PTR0670   00012
00151         DELT=TS-TEMP                                                 PTR0680   00013
00152         F=BUOY*DELT/TS                                               PTR0690   00013
```

TABLE D-1 (Continued)

```
00152     70*     C*** IOPT(13) HOURLY EMISSION INPUT FROM TAPE/DISK?  0=NO, 1=YES.        PTR0700    00013
00153     71*          IF (IOPT(13).EQ.0) GO TO 20                                         PTR0710    00013
00153     72*     C***MODIFY EXIT VELOCITY AND BUOYANCY BY RATIO OF HOURLY EMISSIONS       PTR0720    00013
00153     73*     C***TO AVERAGE EMISSIONS                                                 PTR0730    00013
00155     74*          SCALE=SOURCE(IPOL,J)/PSAV(J)                                        PTR0740    00013
00156     75*          VS=VS*SCALE                                                         PTR0750    00014
00157     76*          F=F*SCALE                                                           PTR0760    00014
00160     77*     20   D=SOURCE(7,J)                                                       PTR0770    00015
00160     78*     C***CALCULATE  H PRIME WHICH TAKES INTO ACCOUNT STACK DOWNWASH           PTR0780    00015
00160     79*     C***BRIGGS(1973) PAGE 4                                                  PTR0790    00015
00161     80*          HPRM=THT                                                            PTR0800    00015
00162     81*          DUM=VS/UPL                                                          PTR0810    00015
00163     82*          IF (DUM.LT.1.5) HPRM=THT+2.*D*(DUM-1.5)                             PTR0820    00015
00165     83*          IF (HPRM.LT.0.) HPRM=0.                                             PTR0830    00017
00165     84*     C***                                                                     PTR0840    00017
00165     85*     C***CALCULATE PLUME RISE AND ADD H PRIME TO OBTAIN EFFECTIVE             PTR0850    00017
00165     86*     C***STACK HEIGHT.                                                        PTR0860    00017
00165     87*     C***                                                                     PTR0870    00017
00165     88*     C***PLUME RISE CALCULATION                                               PTR0880    00017
00167     89*          TEST = VS*TS                                                                NEW00017
00170     90*      330 FORMAT( 10X, / )                                                            NEW00020
00171     91*      331 FORMAT( 10X, I5, 3F10.1 )                                                   NEW00020
00172     92*          IF (KST.GT.4) GO TO 40                                              PTR0890    00020
00172     93*     C***PLUME RISE FOR UNSTABLE CONDITIONS                                   PTR0900    00020
00174     94*          IF (TS.LT.TEMP) GO TO 50                                            PTR0910    00020
00176     95*          IF (F.GE.55.) GO TO 30                                              PTR0920    00021
00176     96*     C***DETERMINE DELTA-T FOR BUOYANCY-MOMENTUM CROSSOVER(F<55)              PTR0930    00021
00176     97*     C***FOUND BY EQUATING BRIGGS(1969) EQ 5.2, PAGE 59 WITH COMBINATION OF   PTR0940    00021
00176     98*     C***BRIGGS(1971) EQUATIONS 6 AND 7, PAGE 1031 FOR F<55.                  PTR0950    00021
00200     99*          DTMB=0.0297*TS*VS**0.33333/D**0.66667                               PTR0960    00021
00201    100*          IF (DELT.LT.DTMB) GO TO 50                                          PTR0970    00023
00201    101*     C***DISTANCE OF FINAL BUOYANT RISE(0.049 IS 14*3.5/1000)                 PTR0980    00023
00201    102*     C***BRIGGS(1971) EQUATION 7,F<55, AND DIST TO FINAL RISE IS 3.5 XSTAR    PTR0990    00023
00203    103*          DISTF=0.049*F**0.625                                                PTR1000    00023
00203    104*     C***COMBINATION OF BRIGGS(1971) EQUATIONS 6 AND 7, PAGE 1031 FOR F<55.   PTR1010    00023
00204    105*          HF=HPRM+21.425*F**0.75/UPL                                          PTR1020    00024
00205    106*          PRINT 331, KST, HPRM, HF                                                    NEW00025
00212    107*          IF( TEST .GT. 12500. ) HF = (HF-HPRM)*0.70 + HPRM                           NEW
00214    108*          PRINT 331, KST, HPRM, HF, TEST                                              NEW00027
00222    109*          GO TO 70                                                            PTR1030
00222    110*     C***DETERMINE DELTA-T FOR BUOYANCY-MOMENTUM CROSSOVER(F>55)              PTR1040
00222    111*     C***FOUND BY EQUATING BRIGGS(1969) EQ 5.2, PAGE 59 WITH COMBINATION OF   PTR1050
00222    112*     C*** BRIGGS(1971) EQUATIONS 6 AND 7, PAGE 1031 FOR F>55.                 PTR1060
```

TABLE D-1 (Continued)

```
00223      30     DTMB=0.00575*TS*VS**0.66667/D**0.33333                         PTR1070    0002
00224             IF (DELT.LT.DTMB) GO TO 50                                      PTR1080    0003
00224      C***DISTANCE OF FINAL BUOYANT RISE (0.119 IS 34*3.5/1000)              PTR1090    0003
00224      C***BRIGGS(1971) EQUATION 7, F>55, AND DIST TO FINAL RISE IS 3.5 XSTAR. PTR1100   0003
00226             DISTF=0.119*F**0.4                                              PTR1110    0003
00226      C***COMBINATION OF BRIGGS(1971) EQUATIONS 6 AND 7, PAGE 1031 FOR F>55  PTR1120    0003
00227             HF=HPRM+38.71*F**0.6/UPL                                        PTR1130    0003
00230             PRINT 331, KST, HPRM, HF                                                NEW0003
00235             IF( TEST .GT. 1500. ) HF = (HF-HPRM)*0.70 + HPRM                         NEW
00237             PRINT 331, KST, HPRM, HF, TEST                                          NEW0003
00245             PRINT 330                                                               NEW
00247             GO TO 70                                                        PTR1140
00247      C***PLUME RISE FOR STABLE CONDITIONS.                                  PTR1150
00250      40     DTHDZ=0.02                                                      PTR1160    0003
00251             IF (KST.GT.5) DTHDZ=0.035                                       PTR1170    0003
00253             S=9.80616*DTHDZ/TEMP                                            PTR1180    0003
00254             IF (TS.LT.TEMP) GO TO 60                                        PTR1190    0003
00254      C***DETERMINE DELTA-T FOR BUOYANCY-MOMENTUM CROSSOVER(STABLE)          PTR1200    0003
00254      C***FOUND BY EQUATING BRIGGS(1975) EQ 59, PAGE 96 FOR STABLE BUOYANCY  PTR1210    0003
00254      C***RISE WITH BRIGGS(1969) EQ 4.28, PAGE 59 FOR STABLE MOMENTUM RISE.  PTR1220    0003
00256             DTMB=0.019582*TEMP*VS*SQRT(S)                                   PTR1230    0003
00257             IF (DELT.LT.DTMB) GO TO 60                                      PTR1240    00041
00257      C***STABLE BUOYANT RISE FOR WIND CONDITIONS.(WIND NOT ALLOWED LOW      PTR1250    00041
00257      C***ENOUGH IN RAM TO REQUIRE STABLE RISE IN CALM CONDITIONS.)          PTR1260    00041
00257      C***BRIGGS(1975) EQ 59, PAGE 96.                                       PTR1270    00041
00261             HF=HPRM+2.6*(F/(UPL*S))**0.333333                               PTR1280    00041
00261      C***COMBINATION OF BRIGGS(1975) EQ 48 AND EQ 59. NOTE DISTF IN KM.     PTR1290    00041
00262             DISTF=0.0020715*UPL/SQRT(S)                                     PTR1300    00042
00263             GO TO 70                                                        PTR1310    00043
00263      C***UNSTABLE-NEUTRAL MOMENTUM RISE                                     PTR1320    00043
00263      C***BRIGGS(1969) EQUATION 5.2, PAGE 59 NOTE: MOST ACCURATE WHEN VS/U>4: PTR1330   00043
00263      C***TENDS TO OVERESTIMATE RISE WHEN VS/U<4 (SEE BRIGGS(1975) PAGE 78,  PTR1340    00043
00263      C*** FIGURE 4.)                                                        PTR1350    00043
00264      50     HF=HPRM+3.*VS*D/UPL                                             PTR1360    00044
00265             DISTF=0.                                                        PTR1370    00044
00266             GO TO 70                                                        PTR1380    00044
00266      C***STABLE MOMENTUM RISE                                               PTR1390    00044
00267      60     DHA=3.*VS*D/UPL                                                 PTR1400    00045
00267      C***BRIGGS(1969) EQUATION 4.28, PAGE 59                                PTR1410    00045
00270             DELHF=1.5*(VS*VS*D*D*TEMP/(4.*TS*UPL))**0.333333/S**0.166667    PTR1420    00045
00271             IF (DHA.LT.DELHF) DELHF=DHA                                     PTR1430    00050
00273             HF=HPRM+DELHF                                                   PTR1440    00051
00274             DISTF=0.                                                        PTR1450    00051
```

TABLE D-1 (Continued)

```
00274   C***STORE OFF PLUME HEIGHT(ETC.) FOR THIS SOURCE FOR USE WITH              PTR1460   000514
00274   C***OTHER RECEPTORS.                                                       PTR1470   000514
00275   70    HSAV(J)=HF                                                           PTR1480   000516
00276         DSAV(J)=DISTF                                                        PTR1490   000517
00277         UPH(J)=UPL                                                           PTR1500   000521
00300         HPR(J)=HPRM                                                          PTR1510   000523
00301         FP(J)=F                                                              PTR1520   000525
00301   C***IF SOURCE-RECEPTOR DISTANCE IS GREATER OR EQUAL TO DISTANCE TO FINAL   PTR1530   000525
00301   C***SKIP PLUME RISE CALCULATION AND USE FINAL RISE.                        PTR1540   000525
00302   80    IF (X.GE.DSAV(J)) GO TO 90                                           PTR1550   000530
00302   C***PLUME RISE FOR DISTANCE X(160 IS 1.6*1000**.67 BECAUSE X IN KM)        PTR1560   000530
00304         HX=HPR(J)+160.*FP(J)**0.333333*X**0.666667/UPH(J)                    PTR1570   000533
00305         IF (HX.LT.HF) HF=HX                                                  PTR1580   000553
00305   C***SUBROUTINE DBTRCR RETURNS THE DISPERSION PARAMTERS,SY AND SZ(METERS)   PTR1590   000553
00305   C***AND RELATIVE CONCENTRATION VALUE CHI/Q (SEC/M**3)                      PTR1600   000553
00307   90    UPL=UPH(J)                                                           PTR1610   000562
00310         CALL DBTRCR (UPL,Z,HF,HL,X,Y,KST,SY,SZ,PROD)                         PTR1620   000563
00310   C***CALCULATE TRAVEL TIME IN KM-SEC/M TO INCLUDE DECAY RATE OF POLLUTANT   PTR1630   000563
00311         TT=X/UPL                                                             PTR1640   000601
00311   C***TLOS IN METERS/KM-SEC, SO TT*TLOS IS DIMENSIONLESS                     PTR1650   000601
00312         PROD=PROD*SOURCE(IPOL,J)/EXP(TT*TLOS)                                PTR1660   000604
00312   C***INCREMENT CONCENTRATION AT K-TH RECEPTOR(G/M**3)                       PTR1670   000604
00313         PCHI(K)=PCHI(K)+PROD                                                 PTR1680   000617
00314         PHCHI(K)=PHCHI(K)+PROD                                               PTR1690   000621
00315         KSIG=IPSIGS(J)                                                       PTR1700   000624
00316         IF (KSIG.EQ.0) GO TO 100                                             PTR1710   000626
00316   C***STORE CONCENTRATIONS FROM SIGNIFICANT SOURCES.(G/M**3)                 PTR1720   000626
00320         PSIGS(K,KSIG)=PSIGS(K,KSIG)+PROD                                     PTR1730   000630
00321         PHSIGS(K,KSIG)=PHSIGS(K,KSIG)+PROD                                   PTR1740   000636
00322         PSIGS(K,26)=PSIGS(K,26)+PROD                                         PTR1750   000641
00323         PHSIGS(K,26)=PHSIGS(K,26)+PROD                                       PTR1760   000644
00324   100   PARTC(J)=PROD                                                        PTR1770   000650
00325   110   CONTINUE                                                             PTR1780   000656
00325   C***END OF LOOP FOR SOURCES                                                PTR1790   000656
00325   C***WRITE PARTIAL CONCENTRATIONS ON DISK(G/M**3)                           PTR1800   000656
00327         IF (IOPT(8).EQ.0) GO TO 120                                          PTR1810   000656
00327   C***USER PLEASE NOTE: PARTIAL CONC. IN G/M**3, NOT MICROGRAM/M**3          PTR1820   000656
00331         WRITE (NIP) IDATE,LH,K,(PARTC(J),J=1,NPT)                            PTR1830   000660
00342   120   CONTINUE                                                             PTR1840   000670
00342   C***END OF LOOP FOR RECEPTORS                                              PTR1850   000670
00344         RETURN                                                               PTR1860   000670
00344   C                                                                          PTR1870   000670
00345         END                                                                  PTR1880   000733
```

TABLE D-2

CRSTER CODE LISTING - PLUME RISE MODIFICATION

```
@FOR,RS CARL.BEH072
FOR S 4R1    T -08/17/79-17:04:27 (1,)

   SUBROUTINE BEH072     ENTRY POINT 000313

   STORAGE USED: CODE(1) 000427; DATA(0) 000046; BLANK COMMON(2) 000000

    COMMON BLOCKS:

    0003     FIX      000001

   EXTERNAL REFERENCES (BLOCK, NAME)

    0004     NER2$
    0005     XPRR

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001     000065 10L        0001     000131 14L        0001     000005 2L         0001     000174 20L        0001
    0001     000214 23L        0001     000236 24L        0001     000252 27L        0001     000274 29L        0001
    0001     000302 31L        0001     000012 4L         0001     000022 6L         0001     000046 7L         0001
    0000 R 000003 DHA          0000     000004 DYN$       0003 I 000000 IS          0000 R 000002 S           0000 R
    0000 R 000000 XST


00101      1*           SUBROUTINE BEH072   (HF,HX,HMW,F,DELHF,DISTF,DELHX,HP,TS,VS,D,VF, BE000100    00000
00101      2*          1 KST,U,X,DTHDZ,T,P)                                                BE000200    00000
00103      3*           COMMON /FIX/ IS                                                                00000
00103      4*     C         BEH072    (BRIGGS EFFECTIVE HEIGHT)    OCTOBER 1972            BE000300    00000
00103      5*     C          THIS DIFFERS FROM THE AUGUST 1972 VERSION IN STATEMENT 24 + 1:BE000400    00000
00103      6*     C           THE CONSTANT 2.4 PREVIOUSLY WAS 2.9, AND IN STATEMENT 27:    BE000500    00000
00103      7*     C           THE CONSTANT 3.14159 PREVIOUSLY WAS 2.4 .                    BE000600    00000
00103      8*     C         D. B. TURNER, RESEARCH METEOROLOGIST* MODEL DEVELOPMENT BRANCH,BE000700    00000
00103      9*     C          DIVISION OF METEOROLOGY, ENVIRONMENTAL PROTECTION AGENCY.     BE000800    00000
00103     10*     C           ROOM 314B, NCHS BUILDING, RTP. PHONE (919) 549-8411 EXT 4564BE000900    00000
00103     11*     C           MAILING ADDRESS- DM, EPA, RESEARCH TRIANGLE PARK, NC 27711   BE001000    00000
00103     12*     C          * ON ASSIGNMENT FROM NATIONAL OCEANIC AND ATMOSPHERIC         BE001100    00000
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TABLE D-2 (Continued)

```
00103   C            ADMINISTRATION, DEPARTMENT OF COMMERCE.                BE001200   000000
00103   C      FROM A SINGLE SOURCE IS BASED ON:                            BE001300   000000
00103   C      THIS VERSION OF BRIGGS EFFECTIVE HEIGHT TO CALCULATE PLUME RISEBE001400   000000
00103   C         1) BRIGGS, GARY A., 1971: SOME RECENT ANALYSES OF PLUME RISE BE001500   000000
00103   C            OBSERVATION. PP 1029 - 1032 IN PROCEEDINGS OF THE SECONDBE001600   000000
00103   C            INTERNATIONAL CLEAN AIR CONGRESS, EDITED BY H. M. ENGLUNBE001700   000000
00103   C            AND W. T. BEERY. ACADEMIC PRESS, NEW YORK.             BE001800   000000
00103   C         2) BRIGGS, GARY A.,1972: DISCUSSION ON CHIMNEY PLUMES IN   BE001900   000000
00103   C            NEUTRAL AND STABLE SURROUNDINGS. ATMOS. ENVIRON. 6, 507 BE002000   000000
00103   C            - 510. (JUL 72).                                       BE002100   000000
00103   C      OUTPUT VARIABLES ARE...                                      BE002200   000000
00103   C         HF     FINAL EFFECTIVE PLUME HEIGHT (METERS)              BE002300   000000
00103   C         HX     EFFECTIVE PLUME HEIGHT FOR DISTANCE X (METERS)     BE002400   000000
00103   C         HMW    HEAT OUTPUT OF SOURCE (MW)                         BE002500   000000
00103   C         F      BUOYANCY FLUX (M**4/SEC**3)                        BE002600   000000
00103   C         DELHF  FINAL PLUME RISE (METERS)                          BE002700   000000
00103   C         DISTF  DISTANCE OF FINAL PLUME RISE FROM SOURCE (KM)      BE002800   000000
00103   C         DELHX  PLUME RISE AT DISTANCE X (METERS)                  BE002900   000000
00103   C      INPUT VARIABLES ARE...                                       BE003000   000000
00103   C         HP     PHYSICAL STACK HEIGHT (METERS)                     BE003100   000000
00103   C         TS     STACK GAS TEMPERATURE (DEG K)                      BE003200   000000
00103   C         VS     STACK GAS EXIT VELOCITY (M/SEC)                    BE003300   000000
00103   C         D      INSIDE STACK DIAMETER (METERS)                     BE003400   000000
00103   C         VF     STACK GAS VOLUMETRIC FLOW RATE (M**3/SEC)          BE003500   000000
00103   C         KST    STABILITY (CLASS), SEE PAGE 209 OF PASQUILL,       BE003600   000000
00103   C                 ATMOSPHERIC DISPERSION.  CLASSES DEFINED BY...    BE003700   000000
00103   C                   1 IS PASQUILL STABILITY CLASS A                 BE003800   000000
00103   C                   2 IS PASQUILL STABILITY CLASS B                 BE003900   000000
00103   C                   3 IS PASQUILL STABILITY CLASS C                 BE004000   000000
00103   C                   4 IS PASQUILL STABILITY CLASS D                 BE004100   000000
00103   C                   5 IS PASQUILL STABILITY CLASS E                 BE004200   000000
00103   C                   6 IS PASQUILL STABILITY CLASS F                 BE004300   000000
00103   C         U      WIND SPEED (M/SEC)                                 BE004400   000000
00103   C         X      DOWNWIND DISTANCE (KM)                             BE004500   000000
00103   C         DTHDZ  POTENTIAL TEMPERATURE LAPSE RATE (DEG K/METER)     BE004600   000000
00103   C         T      AMBIENT AIR TEMPERATURE (DEG K)                    BE004700   000000
00103   C         P      AMBIENT AIR PRESSURE (MB)                          BE004800   000000
00103   C      THANKS TO DALE COVENTRY FOR HIS HELPFUL DISCUSSION ON        BE004900   000000
00103   C      PROGRAMMING PLUME RISE, TO ROGER THOMPSON FOR THE COMMENT    BE005000   000000
00103   C      CARDS, AND TO RUSS LEE WHO REVISED THIS ACCORDING TO REFERENCEBE005100   000000
00104        IF(T)1,1,2                                                     BE005200   000000
00104   C      T = 0. MEANS NO AMBIENT TEMPERATURE GIVEN.  USE T = 293.     BE005300   000000
00107      1 T = 293.                                                       BE005400   000002
```

TABLE D-2 (Continued)

```
00110          2 IF(P)3,3,4                                                  BE005500   00000
00110   C        P = 0. MEANS NO AMBIENT AIR PRESSURE GIVEN.  USE P = 960.   BE005600   00000
00113          3 P = 960.                                                    BE005700   00000
00113   C        IF VF IS NOT GIVEN, CALCULATE IT FROM STACK DATA.           BE005800   00000
00114          4 IF(VF)5,5,6                                                 BE005900   00001
00117          5 VF = 0.785398*VS*D*D                                        BE006000   00001
00117   C        THE CONSTANT 0.785398 = PI/4                                BE006100   00001
00120          6 F = 3.12139*VF*(TS-T)/TS                                    BE006200   00002
00120   C        THE CONSTANT 3.12139 IS THE ACCELERATION DUE TO GRAVITY / PI.  BE006300   00002
00121            HMW = 0.00011217*F*P                                        BE006400   00003
00121   C        THE CONSTANT 0.00011217 = PI TIMES THE SPECIFIC HEAT OF AIR AT BE006500   00003
00121   C         CONSTANT PRESSURE (0.24 CAL/GM*DEG K) TIMES MOLECULAR WEIGHT  BE006600   00003
00121   C         OF AIR (28.966 GM/GM.MOLE) DIVIDED BY IDEAL GAS CONSTANT      BE006700   00003
00121   C         (0.0831 MB*M**3/GM.MOLE*DEG K) AND ACCELERATION DUE TO GRAVITYBE006800   00003
00121   C         (9.80616 M/SEC*SEC) AND THEN MULTIPLIED BY (4.1855E-06 MW/CAL BE006900   00003
00121   C         PER SEC) TO CONVERT THE ANSWER TO MEGAWATTS.                  BE007000   00003
00121   C        GO TO APPROPRIATE BRANCH FOR STABILITY CONDITION GIVEN.     BE007100   00003
00121   C        IF UNSTABLE OR NEUTRAL GO TO 7. IF STABLE GO TO 20.         BE007200   00003
00122            GO TO (7,7,7,7,20,20),KST                                   BE007300   00003
00122   C        DETERMINE APPROPRIATE FORMULA FOR CALCULATING XST, DISTANCE AT BE007400   00003
00122   C         WHICH TURBULENCE BEGINS TO DOMINATE.  THE FORMULA USED DEPENDSBE007500   00003
00122   C         UPON BUOYANCY FLUX. STATEMENTS 8 AND 9 ARE EQUATION (7).      BE007600   00003
00123   7        IF(F-55.)8,9,9                                              BE007700   00004
00126   8        XST=14.*F**.625                                             BE007800   00005
00127            GO TO 10                                                    BE007900   00005
00130   9        XST=34.*F**.4                                               BE008000   00006
00131   10       DISTF=3.5*XST                                               BE008100   00006
00132            DELHF=1.6*F**0.333333*DISTF**0.666667/U                     BE008200   00006
00133            IF(KST.LE.4 .AND. IS.LE.1) DELHF = 0.7*DELHF                          NEW000010
00135            IF(X)29,29,32                                               BE008300   00012
00135   C        IF X = 0.0, CALCULATE FINAL RISE ONLY, IF X IS GREATER THAN  BE008400   00012
00135   C         0.0, CALCULATE RISE FOR DISTANCE = X ALSO.                 BE008500   00012
00140         32 XM = 1000.* X                                               BE008600   00012
00140   C        XM IS X IN METERS.                                          BE008700   00012
00140   C        STATEMENT 14 IS EQUATION (6), REFERENCE 1.                  BE008800   00012
00141         14 DELHX = 1.6*F**0.333333*XM**0.666667/U                      BE008900   00013
00142            IF(DELHX.GT.DELHF)DELHX=DELHF                               BE009000   00014
00144            IF(KST.LE.4 .AND. IS.LE.1) DELHX = 0.7*DELHX                          NEW000015
00146            GO TO 30                                                    BE009100   00017
00147         20 IF(DTHDZ)21,21,24                                           BE009200   00017
00147   C        IF DTHDZ IS NEGATIVE OR ZERO ASSIGN TO IT A VALUE OF 0.02 OR BE009300   00017
00147   C         0.035 IF STABILITY IS SLIGHTLY STABLE OR STABLE, RESPECTIVELY.BE009400   00017
00152         21 GO TO (7,7,7,7,22,23),KST                                   BE009500   00017
```

TABLE D-2 (Continued)

```
00153          22 DTHDZ = 0.02                                                  RE009600   00021
00154             GO TO 24                                                      RE009700   00021
00155          23 DTHDZ = 0.035                                                 RE009800   00021
00156          24 S = 9.80616*DTHDZ/T                                           RE009900   00021
00156      C         THE CONSTANT 9.80616 IS THE ACCELERATION DUE TO GRAVITY.   RE010000   00021
00156      C         S IS A STABILITY PARAMETER.                                RE010100   00021
00156      C         CALCULATE PLUME RISE ACCORDING TO EQUATION (4), REFERENCE 1.  RE010200   00021
00157             DHA = 2.4*(F/(U*S))**0.333333                                 RE010300   00022
00157      C         CALCULATE PLUME RISE BY EQUATION (5), REFERENCE 1 FOR LIGHT   RE010400   00022
00157      C          WIND CONDITIONS ACCORDING TO MORTON, TAYLOR, AND TURNER.  RE010500   00022
00160             DELHF = 5.0*F**0.25/S**0.375                                  RE010600   00023
00161             IF(DHA-DELHF) 25,25,27                                        RE010700   00024
00164          25 DELHF = DHA                                                   RE010800   00024
00164      C         DISTANCE TO FINAL PLUME RISE IS GIVEN BY THE FOLLOWING     RE010900   00024
00165          27 DISTF = 3.14159*U/S**0.5                                      RE011000   00025
00165      C         IF X = 0.0, CALCULATE FINAL RISE ONLY, IF X IS GREATER THAN  RE011100   00025
00165      C          0.0, CALCULATE RISE FOR DISTANCE = X ALSO.                RE011200   00025
00165      C         IF X IS ZERO OR LESS, GO TO 29 AND SET PLUME RISE AND DIST. TO  RE011300   00025
00165      C          MAXIMUM PLUME RISE EQUAL TO ZERO.                         RE011400   00025
00166             IF(X)29,29,33                                                 RE011500   00026
00171          33 XM = 1000.*X                                                  RE011600   00026
00171      C         XM IS X IN METERS.                                         RE011700   00026
00171      C         IF XM IS GREATER THAN THE DISTANCE TO THE POINT OF FINAL PLUME  RE011800   00026
00171      C          RISE, SET PLUME RISE EQUAL TO FINAL PLUME RISE, OTHERWISE,  RE011900   00026
00171      C          CALCULATE PLUME RISE FROM EQUATION (6),REFERENCE 1.       RE012000   00026
00172             IF(XM-DISTF)14,14,28                                          RE012100   00026
00175          28 DELHX = DELHF                                                 RE012200   00027
00176             GO TO 30                                                      RE012300   00027
00177          29 DELHX = 0.                                                    RE012400   00027
00200             HX = 0.                                                       RE012500   00027
00201             GO TO 31                                                      RE012600   00027
00201      C         CALCULATE EFFECTIVE HEIGHT AT DISTANCE X.                  RE012700   00027
00202          30 HX = HP + DELHX                                               RE012800   00027
00202      C         CALCULATE FINAL EFFECTIVE HEIGHT.                          RE012900   00027
00203          31 HF = HP + DELHF                                               RE013000   00030
00204             DISTF = DISTF/1000.                                           RE013100   00030
00205             RETURN                                                        RE013200   00030
00206             END                                                           RE013300   00042

END OF COMPILATION:        NO DIAGNOSTICS.
```

TABLE D-3

TCM CODE LISTING - PLUME RISE MODIFICATION

```
1251          DO 4235 IP=1,NPOL                                            TCM57600
1254          AF(IP)=AN(IRUN,IP)                                           TCM57700
1255    4235  BF(IP)=BN(IRUN,IP)                                           TCM57800
1255    C                                                                  TCM57900
1255    C   INPUT POINT SOURCE DATA                                        TCM58000
1255    C     X = X-COORDINATE, KILOMETERS                                 TCM58100
1255    C     Y = Y-COORDINATE, KILOMETERS                                 TCM58200
1255    C     E(N) = EMISSION RATE OF POLLUTANT N, GRAMS/SECOND.           TCM58300
1255    C     H = SOURCE HEIGHT, METERS                                    TCM58400
1255    C     D = SOURCE DIAMETER, METERS                                  TCM58500
1255    C     V = EXIT VELOCITY, METERS/SECOND                             TCM58600
1255    C     T = EXIT TEMPERATURE, DEGREES CENTIGRADE                     TCM58700
1255    C   POINT SOURCE FORMAT IS SET UP FOR CDM (ONLY 2 POLLUTANTS)      TCM58800
1255    C     TO USE 3 POLLUTANTS, FORMATS 227 AND 945 MUST BE CHANGED.    TCM58900
1257    4242  READ(IRD,227)X,Y,E(1),E(2),H,D,V,T,SID                       TCM59000
1275    227   FORMAT(F6.0,F7.0,7X,2F8.0,F7.0,F5.0,2F7.0,7X,2A4)            TCM59100
1276          IF(X+Y+E(1)+E(2).LT.0.01) GO TO 355                          TCM59200
1300          IPT= IPT+1                                                   TCM59300
1301          T=T+273.15                                                   TCM59400
1302          IF(NCSOPT.EQ.0) GO TO 228                                    TCM59500
1304          IF(NCSOPT.EQ.2) E(1)= E(2)                                   TCM59600
1306          IF(NCSOPT.EQ.3) E(1)= E(3)                                   TCM59700
1310          E(2)=0.                                                      TCM59800
1311          E(3)=0.                                                      TCM59900
1312    228   IF((IPT-1)/50*50.NE.IPT-1) GO TO 240                         TCM60000
1314          WRITE(IWR,900)                                               TCM60100
1316          WRITE(IWR,935)TT,IRUN                                        TCM60200
1325          WRITE(IWR,940)                                               TCM60300
1327    240   WRITE(IWR,945)IPT,X,Y,H,D,V,T,E(1),E(2),SID                  TCM60400
1327    C                                                                  TCM60500
1327    C   CALCULATE BRIGGS PLUME RISE                                    TCM60600
1327    C     HH IS EFFECTIVE STACK HEIGHT                                 TCM60700
1346          FB= 2.45*V*D*D*(T-TA(IRUN))/T                                TCM60800
1347          IF(FB.GT.55.) GO TO 230                                      TCM60900
1351          XA35=49.0*FB**0.625                                          TCM61000
1352          GO TO 235                                                    TCM61100
1353    230   XA35=119.0*FB**0.4                                           TCM61200
1354    235   DO 265 IS=1,6                                                TCM61300
1357          VUF(IS)= ((10./H)**P(IS))/U(IS,IRUN)                         TCM61400
1360    265   HH(IS)= H + 1.6*VUF(IS)*(FB**0.333333)*XA35**0.666667        TCM61500
1360    C                                                                      *NEW
1360    C     MODIFICATION FOR TURBINE PLUME RISE                              *NEW
1360    C     PLUME RISE FOR STABLE CONDITIONS (A THROUGH DN ) = .7*BRIGGS 71  *NEW
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TABLE D-3 (Continued)

```
1360   C                                                                     *NEW
1362     977 FORMAT(10X, I5, 3F10.1)                                          *NEW
1363     978 FORMAT(10X,/)                                                    *NEW
1364         TEST = (T+273.2)*V                                               *NEW
1365         DO 266 JK = 1,4                                                  *NEW
1370         PRINT 977, J, H, HH(JK)                                          *NEW
1375         IF(TEST .GT. 12500.) HH(JK) = (HH(JK) - H)*0.7 + H               *NEW
1377         PRINT 977, J, H, HH(JK), TEST                                    *NEW
1405         PRINT 978                                                        *NEW
1407     266 CONTINUE                                                         *NEW
1411         VUM=((10./H)**0.25)/UMEAN(IRUN)                           TCM61600
1411   C   CALCULATE DECAY FACTORS FOR EACH POLLUTANT FOR 20 DOWNWIND DISTANCESTCM61700
1411   C    TO 46.1 KM., USING MEAN INVERSE WIND SPEED AT PHYSICAL STACK HEIGHTTCM61800
1412         DO 268 ID=1,20                                            TCM61900
1415         DIST=DLIM(ID)*1000.                                       TCM62000
1416         DO 268 IP=1,NPOL                                          TCM62100
1421   268   DECAY(ID,IP)=EXP(-0.692*DIST*VUM/HALF(IP))                TCM62200
1421   C   FOR EACH STABILITY CLASS, DETERMINE FACTORS NSH,FSH FOR     TCM62300
1421   C    INTERPOLATION TO CORRECT EFFECTIVE STACK HEIGHT IN KPS TABLE.TCM62400
1424         DO 285 I=1,6                                              TCM62500
1427         IF(HH(I).GT.10.) GO TO 269                                TCM62600
1431         NSH(I)=1                                                  TCM62700
1432         FSH(I)=1.                                                 TCM62800
1433         GO TO 285                                                 TCM62900
1434   269   IF(HH(I).LT.300.) GO TO 270                               TCM63000
1436         NSH(I)=8                                                  TCM63100
1437         FSH(I)=0.                                                 TCM63200
1440         GO TO 285                                                 TCM63300
1441   270   DO 272 J=2,9                                              TCM63400
1444   272   IF(HH(I).LE.HLIM(J)) GO TO 275                            TCM63500
1447   275   NSH(I)=J-1                                                TCM63600
1450         FSH(I)= (HLIM(J)-HH(I))/(HLIM(J)-HLIM(J-1))               TCM63700
1451   285   CONTINUE                                                  TCM63800
1451   C                                                               TCM63900
1451   C   CALCULATE CONCENTRATIONS FROM POINT SOURCE AT THE CENTER    TCM64000
1451   C    OF EACH GRID SQUARE.                                       TCM64100
1453         DO 300 I=1,LX                                             TCM64200
1456         XI=I                                                      TCM64300
1457         XCGS= XSWC + (XI-0.5)*GRID                                TCM64400
1460         XD= XCGS - X                                              TCM64500
1461         XDSQ= XD*XD                                               TCM64600
1462         DO 300 J=1,LY                                             TCM64700
1465         YJ=J                                                      TCM64800
```

TABLE D-4

RAM SUBROUTINE PGSYSZ LISTING - DOWNWASH MODIFICATION

```
@FOR,S PGSYSZ,PGSYSZ
FOR S 4R1    T -08/20/79-17:56:51 (0,)

   SUBROUTINE PGSYSZ     ENTRY POINT 000370

   STORAGE USED: CODE(1) 000440; DATA(0) 000046; BLANK COMMON(2) 000000

    COMMON BLOCKS:

    0003    DW      000147
    0004    BLD     000002

   EXTERNAL REFERENCES (BLOCK, NAME)

    0005    DOWAZY
    0006    NER2$
    0007    RMATH$
    0010    ALOG$
    0011    XPRR$
    0012    SIN$
    0013    COS$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001     000045 1L        0001     000071 10L       0001     000117 12L       0001     000106 172G      0001     00
    0001     000131 20L       0001     000146 207G      0001     000157 22L       0001     000220 225G      0001     00
    0001     000310 253G      0001     000171 30L       0001     000207 40L       0001     000231 42L       0001     00
    0001     000265 52L       0001     000277 60L       0001     000321 62L       0001     000333 69L       0001     00
    0001     000344 71L       0003 R   000037 AA        0003 R   000057 AB        0003 R   000065 AD        0003 R   00
    0003 R   000123 AF        0003 R   000047 BA        0003 R   000062 BB        0003 R   000073 BD        0003 R   00
    0003 R   000135 BF        0000     000007 DYN$      0004 R   000000 HT        0000 R   000002 HTT       0000 I   00
    0000 R   000001 SAVEX     0000 R   000005 TH        0000 R   000003 VX        0000 R   000004 VY        0004 R   00
    0003 R   000000 XA        0003 R   000007 XB        0003 R   000011 XD        0003 R   000016 XE        0003 R   00
    0000 R   000000 XY


00101      1*          SUBROUTINE PGSYSZ (X,KST,SY,SZ)                                              000000
```

TABLE D-4 (Continued)

```
00101    C        D. B. TURNER, ENVIRONMENTAL APPLICATIONS BRANCH                        000000
00101    C         METEOROLOGY LABORATORY, ENVIRONMENTAL PROTECTION AGENCY               000000
00101    C          RESEARCH TRIANGLE PARK, N C 27711                                    000000
00101    C              (919) 549 - 8411, EXTENSION 4565                                 000000
00101    C        VERTICAL DISPERSION PARAMETER VALUE, SZ DETERMINED BY                  000000
00101    C         SZ = A * X ** B WHERE A AND B ARE FUNCTIONS OF BOTH STABILITY         000000
00101    C         AND RANGE OF X.                                                       000000
00101    C        HORIZONTAL DISPERSION PARAMETER VALUE, SY DETERMINED BY                000000
00101    C         LOGARITHMIC INTERPOLATION OF PLUME HALF-ANGLE ACCORDING TO            000000
00101    C         DISTANCE AND CALCULATION OF 1/2.15 TIMES HALF-ARC LENGTH.             000000
00103          COMMON/DW/XA(7),XB(2),XD(5),XE(8),XF(9),AA(8),BA(8),AB(3),BB(3),       NEW000000
00103         *AD(6),BD(6),AE(9),BE(9),AF(10),BF(10)                                  NEW000000
00104          COMMON/BLD/HT,WD                                                       NEW000000
00105          DATA XA/.5,.4,.3,.25,.2,.15,.1/                                        -2000000
00107          DATA XB/.4,.2/                                                          000000
00111          DATA XD /30.,10.,3.,1.,.3/                                              000000
00113          DATA XE /40.,20.,10.,4.,2.,1.,.3,.1/                                    000000
00115          DATA XF /60.,30.,15.,7.,3.,2.,1.,.7,.2/                                 000000
00117          DATA AA /453.85,346.75,258.89,217.41,179.52,170.22,158.08,122.8/        000000
00121          DATA BA /2.1166,1.7283,1.4094,1.2644,1.1262,1.0932,1.0542,.9447/        000000
00123          DATA AB /109.30,98.483,90.673/                                          000000
00125          DATA BB /1.0971,0.98332,0.93198/                                        000000
00127          DATA AD /44.053,36.650,33.504,32.093,32.093,34.459/                     000000
00131          DATA BD /0.51179,0.56589,0.60486,0.64403,0.81066,0.86974/               000000
00133          DATA AE /47.618,35.420,26.970,24.703,22.534,21.628,21.628,23.331,       000000
00133         1 24.26/                                                                 000000
00135          DATA BE /0.29592,0.37615,0.46713,0.50527,0.57154,0.63077,0.75660,       000000
00135         1 0.81956,0.8366/                                                        000000
00137          DATA AF /34.219,27.074,22.651,17.836,16.187,14.823,13.953,13.953,       000000
00137         1 14.457,15.209/                                                         000000
00141          DATA BF /0.21716,0.27436,0.32681,0.41507,0.46490,0.54503,0.63227,       000000
00141         1 0.68465,0.78407,0.81558/                                               000000
00143         XY=X                                                                     000000
00144         SAVEX=X                                                                 NEW000001
00145         IF(HT.LE.0.) GO TO 2                                                    NEW000002
00147         HTT=HT/100.                                                             NEW000005
00150         IF(X.GE.HTT) GO TO 1                                                    NEW000010
00152         SY=.35*WD+.067*(1000.*X-3.*HT)                                          NEW000013
00153         SZ=.7*HT+.067*(1000.*X-3.*HT)                                           NEW000025
00154         IF(SZ.LE.0.) SZ=1.                                                      NEW000031
00156         IF(SY.LE.0.) SY=1.                                                      NEW000036
00160         RETURN                                                                  NEW000043
00161       1 CALL DOWAZY(X,KST,VX,VY)                                                NEW000045
```

TABLE D-4 (Continued)

```
00162            X=VX+X                                          NEW000051
00163            XY=VY+X                                         NEW000054
00164          2 CONTINUE                                        NEW000057
00165            GO TO (10,20,30,40,50,60),KST                      000057
00165      C        STABILITY A (10)                                000057
00166         10 TH = (24.167 - 2.5334*ALOG(XY))/57.2958            000071
00167            IF (X.GT.3.11) GO TO 69                            000077
00171            DO 11 ID = 1,7                                     000106
00174            IF(X.GE.XA(ID)) GO TO 12                           000106
00176         11 CONTINUE                                           000114
00200            ID = 8                                             000114
00201         12 SZ = AA(ID) * X ** BA(ID)                          000117
00202            GO TO 71                                           000127
00202      C        STABILITY B (20)                                000127
00203         20 TH = (18.333 - 1.8096*ALOG(XY))/57.2958            000131
00204            IF(X.GT.35.) GO TO 69                              000137
00206            DO 21 ID = 1,2                                     000146
00211            IF (X.GE.XB(ID)) GO TO 22                          000146
00213         21 CONTINUE                                           000154
00215            ID = 3                                             000154
00216         22 SZ = AB(ID) * X ** BB(ID)                          000157
00217            GO TO 70                                           000167
00217      C        STABILITY C (30)                                000167
00220         30 TH = (12.5 - 1.0857*ALOG(XY))/57.2958              000171
00221            SZ = 61.141 *X ** 0.91465                          000177
00222            GO TO 70                                           000205
00222      C        STABILITY D (40)                                000205
00223         40 TH = (8.3333-0.72382*ALOG(XY))/57.2958             000207
00224            DO 41 ID = 1,5                                     000220
00227            IF (X.GE.XD(ID)) GO TO 42                          000220
00231         41 CONTINUE                                           000226
00233            ID = 6                                             000226
00234         42 SZ = AD(ID) * X ** BD(ID)                          000231
00235            GO TO 70                                           000241
00235      C        STABILITY E (50)                                000241
00236         50 TH = (6.25 - 0.54287*ALOG(XY))/57.2958             000243
00237            DO 51 ID = 1,8                                     000254
00242            IF (X.GE.XE(ID)) GO TO 52                          000254
00244         51 CONTINUE                                           000262
00246            ID = 9                                             000262
00247         52 SZ = AE(ID) * X ** BE(ID)                          000265
00250            GO TO 70                                           000275
00250      C        STABILITY F (60)                                000275
```

TABLE D-4 (Continued)

```
00251        60 TH = (4.1667 - 0.36191*ALOG(XY))/57.2958                000277
00252           DO 61 ID = 1,9                                          000310
00255           IF (X.GE.XF(ID)) GO TO 62                               000310
00257        61 CONTINUE                                                000316
00261           ID = 10                                                 000316
00262        62 SZ = AF(ID) * X ** BF(ID)                               000321
00263           GO TO 70                                                000331
00264        69 SZ = 5000.                                              000333
00265           GO TO 71                                                000334
00266        70 IF (SZ.GT.5000.) SZ = 5000.                             000336
00270        71 SY = 465.116 * XY * SIN(TH) / COS(TH)                   000344
00271           X=SAVEX                                              NEW000360
00271     C        465.116 = 1000. (M/KM) / 2.15                        000360
00272           RETURN                                                  000362
00273           END                                                     000437

     END OF COMPILATION:        NO  DIAGNOSTICS.
```

TABLE D-5

DOWAZY SUBROUTINE LISTING - DOWNWASH MODIFICATION

```
@FOR,IS DOWAZY,DOWAZY
FOR S 4R1    T -08/20/79-17:55:45 (,0)


   SUBROUTINE DOWAZY     ENTRY POINT 000354


   STORAGE USED: CODE(1) 000413; DATA(0) 000074; BLANK COMMON(2) 000000

    COMMON BLOCKS:

    0003     DW       000147
    0004     BLD      000002

   EXTERNAL REFERENCES (BLOCK, NAME)

    0005     NER2$
    0006     RMATH$
    0007     XPRR$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001     000023 100L      0001     000067 110L      0001     000116 12L       0001     000133 120L      0001     00
    0001     000154 130L      0001     000210 140L      0001     000105 145G      0001     000250 150L      0001     00
    0001     000312 161L      0001     000222 174G      0001     000052 2L        0001     000262 210G      0001     00
    0001     000233 42L       0001     000273 52L       0003 R 000037 AA        0003 R 000057 AB        0003 R 00
    0003 R 000101 AE        0003 R 000123 AF        0003 R 000047 BA        0003 R 000062 BB        0003 R 00
    0003 R 000112 BE        0003 R 000135 BF        0000     000043 DYN$      0004 R 000000 HT        0000 I 00
    0000 R 000042 P         0000 R 000037 SIGY      0000 R 000040 SIGZ      0000 R 000000 SZA       0000 R 00
    0000 R 000011 SZD       0000 R 000016 SZE       0000 R 000026 SZF       0004 R 000001 WD        0003     00
    0003     000007 XB        0003     000011 XD        0003     000016 XE        0003     000026 XF


00101           SUBROUTINE DOWAZY(X,KST,VX,VY)                                                      000000
00103           DIMENSION SZA(7),SZB(2),SZD(5),SZE(8),SZF(9)                                        000000
00104           COMMON/DW/XA(7),XB(2),XD(5),XE(8),XF(9),AA(8),BA(8),AB(3),BB(3),                    000000
00104          *AD(6),BD(6),AE(9),BE(9),AF(10),BF(10)                                               000000
00105           COMMON/BLD/HT,WD                                                                    000000
00106           DATA SZA/104.6,71.2,47.4,37.7,29.3,21.4,14./                                        000000
```

TABLE D-5 (Continued)

```
00110            DATA SZB/40.,22.04/                                  000000
00112            DATA SZD/251.3,134.9,65.1,32.1,12.1/                 000000
00114            DATA SZE/141.9,109.3,79.,49.7,33.5,21.6,8.7,3.5/     000000
00116            DATA SZF/83.2,68.7,54.9,40.,27.,21.3,14.,10.9,4.1/   000000
00120            SIGY=.35*WD+.5*HT                                    000000
00121            SIGZ=1.2*HT                                          000005
00122            GO TO (100,110,120,130,140,150), KST                 000010
00122      C           A STABILITY                                    000010
00123        100 VY=(SIGY/210.)**1.124                                000023
00124            IF(SIGZ.GT.5000.) GO TO 160                          000032
00126            DO 1 ID=1,7                                          000041
00131            IF(SIGZ.GE.SZA(ID)) GO TO 2                          000041
00133          1 CONTINUE                                             000047
00135            ID=8                                                 000047
00136          2 P=1./BA(ID)                                          000052
00137            VX=(SIGZ/AA(ID))**P                                  000055
00140            GO TO 161                                            000065
00140      C           B STABILITY                                    000065
00141        110 VY=(SIGY/180.)**1.14                                 000067
00142            IF (SIGZ.GT.5000.) GO TO 160                         000076
00144            DO 11 ID=1,2                                         000105
00147            IF(SIGZ.GE.SZB(ID)) GO TO 12                         000105
00151         11 CONTINUE                                             000113
00153            ID=3                                                 000113
00154         12 P=1./BB(ID)                                          000116
00155            VX=(SIGZ/AB(ID))**P                                  000121
00156            GO TO 161                                            000131
00156      C           C STABILITY                                    000131
00157        120 VY=(SIGY/113.)**1.109                                000133
00160            VX=(SIGZ/61.14)**1.093                               000142
00161            GO TO 161                                            000152
00161      C           D STABILITY                                    000152
00162        130 VY=(SIGY/74.)**1.099                                 000154
00163            IF(SIGZ.GT.SZD(ID)) GO TO 32                         000163
00165         31 CONTINUE                                             000170
00166            ID=6                                                 000170
00167         32 P=1./BD(ID)                                          000173
00170            VX=(SIGZ/AD(ID))**P                                  000176
00171            GO TO 161                                            000206
00171      C           E STABILITY                                    000206
00172        140 VY=(SIGY/52.)**1.089                                 000210
00173            DO 41 ID=1,8                                         000222
00176            IF(SIGZ.GE.SZE(ID)) GO TO 42                         000222
```

TABLE D-5 (Continued)

```
00200           41 CONTINUE                                    000230
00202              ID=9                                        000230
00203           42 P=1./BE(ID)                                 000233
00204              VX=(SIGZ/AE(ID))**P                         000236
00205              GO TO 161                                   000246
00205       C              F STABILITY                         000246
00206          150 VY=(SIGY/35.)**1.099                        000250
00207              DO 51 ID=1,9                                000262
00212              IF(SIGZ.GE.SZF(ID)) GO TO 52                000262
00214           51 CONTINUE                                    000270
00216              ID=10                                       000270
00217           52 P=1./BF(ID)                                 000273
00220              VX=(SIGZ/AF(ID))**P                         000276
00221              GO TO 161                                   000306
00222          160 VX=3.11                                     000310
00223          161 IF (VX.GT.100.) VX=100.                     000312
00225              IF (VY.GT.100.) VY=100.                     000322
00227              VY=VY-(HT/100.)                             000330
00230              VX=VX-(HT/100.)                             000333
00231              IF(VX.LE.0.) VX=0.                          000336
00233              IF(VY.LE.0.) VY=0.                          000342
00235              RETURN                                      000346
00236              END                                         000412

END OF COMPILATION!        NO  DIAGNOSTICS.
```

REFERENCES

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U.S. Environmental Protection Agency, User's Manual for Single Source (CRSTER) Model, EPA-450/2-77-013, Research Triangle Park, NC, 1977.

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APPENDIX E
METEOROLOGICAL DATA

Surface Meteorological Data Used in Modeling

Surface meteorological data used in modeling were obtained from the Barter Island TDF-1440 meteorological tape supplied by the National Climatic Center. These data were complete on arrival. Interpolations necessary for filling in missing data had already been made by the National Climatic Center. For short term modeling, surface data for the year 1964 for Barter Island were used. For annual modeling, annual average meteorological data were obtained from Barter Island surface data for the years 1958-1964.

Mixing Height Data Used in Short Term Modeling

Afternoon mixing height data for Barter Island for the year 1964 were used in short term modeling. These data were obtained from the National Climatic Center and were determined by the Holzworth method. Missing afternoon mixing height data were filled in by Radian through the use of linear interpolation between valid afternoon mixing heights on each side of the missing mixing height. Annual average mixing heights were not needed since the TCM model does not use mixing heights in its computations.

Justification for using Barter Island Surface and Upper Air Data

Barter Island surface and upper air (mixing height) data were selected for use in modeling for the following reasons:

- Barter Island wind data can be considered reasonably representative of wind flow in the study area. As noted in Section 4.0, the Deadhorse Airport surface wind rose for 1976 shows a prevailing east-northeasterly wind while the Barter Island wind rose for the period 1958-1964 shows a prevailing easterly wind. It was noted that the difference in the prevailing wind directions might be the result of:
  (1) The short sampling period at the Deadhorse Airport versus the longer sampling period at Barter Island,
  (2) A large scale effect on the winds at Barter Island created by the Romanzof Mountains south of Barter Island and a smaller effect on the winds at Prudhoe Bay created by the Brooks Range south of Prudhoe Bay, and/or
  (3) The coastal configuration at Prudhoe Bay compared to that at Barter Island.

- There are no significant terrain features on the North Slope of Alaska that will induce large orographic influences in the wind fields at either Prudhoe Bay or Barter Island. The land itself is tundra with very little aerodynamic surface roughness to affect the wind fields.

- Although surface wind data are collected at Deadhorse Airport, which is in the immediate study area, no hourly data were readily available on magnetic tape for this station. Hourly data for this station can be put on magnetic tape by the National Climatic Center or in-house. This process, however, is costly and very lengthy. The Unit

Operators felt that the small increase in validity obtained from the use of Deadhorse Airport did not justify the increased cost or time expenditure.

- Both surface and mixing height data were readily available for Barter Island for the year 1964. The year 1964 is important for short term modeling since it is the most recent year for which hourly surface data are readily available and for which wind direction is indicated to the nearest 10 degrees.

- Barter Island is the closest National Weather Service area for which upper air data are available. Barter Island is approximately 120 miles east of Prudhoe Bay.

- It is desirable in modeling to use surface and upper air data from the same station and for the same period of record.

Stability Calculations by Turner's Method

In both long and short term modeling, stability classifications were derived by Turner's Method (also known as the STAR method) (Turner, 1961, pp. 448) which uses wind speed, wind direction, and cloud cover data from the TDF-1440 surface tape. The six stability classes calculated by Turner's Method are A, B, C, D_1, D_2, and E + F. Classes A, B, and C are the unstable classes, ranging from very unstable (a) to slightly unstable (C). Class D_1 is the neutral class for daytime only, while class D_2 is the neutral class for nighttime only. Class E + F encompass all stable cases. For annual modeling, the Radian version of the STAR program was used to produce the joint frequencies of the sixteen compass point wind directions, the six Pasquill-Gifford stability classes, and six wind speed classes.

There are several potential problems associated with Turner's Method and its application in Alaska and at Barter Island (Prudhoe Bay) in particular.

(1) Turner's Method over estimates the frequency of occurrence of neutral conditions at Barter Island at the expense of stable conditions. This is because wind speed, which is one of the factors used in Turner's Method to estimate stability, causes mechanical turbulence.

Mechanical turbulence in the atmosphere is caused by air flowing over a non-uniform surface with a given aerodynamic surface roughness. The amount of mechanical turbulence generated by the wind increases with increasing wind speed. This turbulence then causes the turbulent layer to become well mixed. As a result, the vertical temperature structure of the turbulent layer approaches the neutral, or dry adiabatic, lapse rate as the surface wind increases.

Turner's stability classification scheme is valid for areas of average surface roughness. The Prudhoe Bay area is a very flat area of tundra with no forests or other significant areas of large vegetation. Seaward is ice pack or open ocean, depending upon the season. The result is that the aerodynamic surface roughness of the Prudhoe Bay area is very low. As a consequence, the average mechanical turbulence generated by wind flowing over the area is correspondingly low. This is not saying that mechanical turbulence is not generated by the wind at Prudhoe Bay. It only implies that the depth through which the mechanical turbulence is significant is much shallower and closer to the surface than would be expected with the same wind speeds elsewhere.

This turbulence is less than the turbulence implicitly contained in Turner's scheme that give stability as a function of wind speed and net radiation at the earth's surface. (Convective turbulence is a function of net radiation.) The result is that Turner's Method will predict that more turbulence driven mixing occurs in the lower atmospheric layers than actually occurs with stability being forced to neutral conditions at higher wind speeds. Actually, vertical temperature gradients will persist at higher wind speeds than predicted by Turner's Method and thus Turner's Method over predicts neutral conditions.

Radian is currently conducting ambient monitoring at Prudhoe Bay. From the data already collected, Radian has identified several days that support the opinion that the surface turbulence layer is very shallow along the Alaska's north slope. In one instance in March 1979, a 6°F inversion was maintained for several hours between 33 feet and 200 feet while the wind speed at 200 feet was 20 mph and that at 33 feet was 16 to 20 mph. At the same time, the horizontal wind direction fluctuation standard deviation, σ_H, at 200 feet was very small, indicating very stable flow conditions.

It appears that on this day, the mechanical turbulence layer caused by the 20 mph wind shear between the ground and 33 feet was totally contained within the first 33 feet of the atmosphere.

The fact that Turner's Method forces stability conditions to neutral is significant for Barter Island since the average wind speed at Barter Island for the period 1958-1964 was 11.5 knots. The maximum solar elevation angle possible at the latitude of Barter Island is about 43.5 degrees on the summer solstice, June 21. The combination of these two factors, high average wind speed and relatively low maximum solar elevation angle restrict the allowable stability class to neutral for about one half of an entire year. There are still many other cases of neutral stability with other wind speeds, with Turner's Method predicting neutral stabilities over 77 percent of the time. Stable conditions account for only 16 percent of all hours.

(2) Turner's Method probably under estimates the occurrence of stable conditions. Stable conditions result when net radiation flux at the earth's surface is negative. This occurs at night when there is no incoming solar, or short wave radiation and there is significant outgoing terrestrial, or long wave, radiation.

During the period around the winter solstice, the sun never rises at Barter Island and Prudhoe Bay. As a result, for the winter months, there is strong and continuous outgoing terrestrial radiation, moderated somewhat by the winter cloud cover. The presence of complete snow cover on the ground during the winter is expected to enhance the net radiation deficit. Snow is an excellent radiator of long wave radiation and will emit more radiation than the bare ground. A net radiation deficit at the surface means that the surface is cooling with respect to the adjacent atmosphere. This condition is then responsible for the formation and maintenance of surface radiational inversions and stable conditions. Without the normal diurnal heating of the sun, these stable conditions can then be expected to persist for extended periods of time.

As a consequence, the extreme winter net radiation deficit, enhanced by the continuous winter darkness and the extensive snow fields, is probably stronger and more persistent than is implicitly allowed for in Turner's Method. Thus, Turner's Method will tend to under predict the occurrence of stable conditions at Barter Island.

Radian has also learned from its ambient monitoring program that there are several elevated stable layers and inversions normally present at Prudhoe Bay in the late winter and spring. The existence of these stable layers cannot be accounted for by Turner's Method, except for a single ground based surface inversion. Undoubtedly, the net radiation deficit during this time of the year is responsible for many of these stable layers and inversions.

(3) Turner's Method requires calculations of sunrises and sunsets in order to estimate incoming solar radiation and outgoing terrestial radiation. These are problems associated with the calculation of sunrise/set during certain times of the year at the northern latitude at Barter Island and Prudhoe Bay. These problems are discussed in detail later in this appendix.

There are several reasons why Turner's Method was considered acceptable for use at Barter Island.

(1) Turner's Method is accepted by the EPA and is included in the PREP, RAMMET, and STAR programs.* Thus, there is no need to rejustify the development of Turner's method since it is an accepted method. All that needs to be done in order to use it is to justify its applicability.

(2) Any modification to Turner's method will make it essentially a new method. As such, its development must be justified to the EPA in detail. A result of this justification process is that the time and effort needed by the EPA to review the

*PREP is a meteorological preprocessor program used with CRSTER, RAMMET generates a meteorological file for RAM, and STAR produces a meteorological joint frequency function for annual models like TEM.

PSD application is greatly increased. The Unit Operators do not feel that development of a new scheme solely for the present PSD application is warranted from an economic, time or increased validity standpoint.

(3) The two major problems with Turner's Method are over-prediction of neutral conditions and under-prediction of stable conditions, both of which produce conservative dispersion modeling results.

Most of the proposed emissions will be from the proposed gas turbine facilities. As such, there will be considerable plume rise associated with the gas turbine emissions. The effective emission height will then be well above the shallow mechanical turbulence layer produced by mechanical wind shear.

Under the predominant stable conditions that will occur at plume height, the plume will be embedded in the stable flow and will only very slowly, if at all, diffuse to the ground. Plume diffusion under neutral conditions is much more rapid, with more pollutant physically being diffused to the ground. Thus, because Turner's Method over predicts neutral regimes and under-predicts stable regimes, plumes actually dispersing under stable conditions at times will be handled by the dispersion models as if the stability were neutral. The result is that higher ground level concentrations will tend to be calculated. Higher ground level concentrations, in turn, produce more conservative estimates of air quality impacts.

Determination of Hourly Mixing Heights

Radian modified the CRSTER meteorological processor PREP to enable it to calculate correctly sunrise and sunset conditions above the Artcic Circle. Sunrise and sunset times are needed by PREP to enable PREP to calculate hourly mixing heights and also to determine hourly stability classes. PREP was also modified so that the hourly mixing heights would be determined by linear interpolation between successive afternoon mixing heights during summer and winter. The normal PREP mixing height interpolation scheme was used during the spring and fall.

Circumpolar Sun Considerations

Prudhoe Bay is different from a geographic point of view compared to most locations where PSD permits must be prepared. Prudhoe Bay is located at about 70°N latitude which is above the Arctic Circle. Because of this, for about 32 days on each side of the summer and winter solstices, the sun is circumpolar, or circles the poles. In other words, the sun is above the horizon continually for 64 days near the summer solstice. The sun is also below the horizon continuously for 64 days near the winter solstice. The dividing line between locations experiencing 24 hour daylight periods or nighttime periods is the Arctic Circle, which is located a 66.55°N.

Meteorological Data and Sunrise/Sunset

The CRSTER dispersion model requires that meteorological information input into the CRSTER model be in a specific format. This formatted meteorological data is produced by the preprocessor program PREP. PREP is identical to the meteorological preprocessor for the RAM model, RAMMET. In both of these programs, the height of the mixing height for each hour is interpolated from twice daily mixing heights input into the program. The mixing height interpolation scheme used is a function of sunrise and sunset at the given location where the meteorological data is valid.

The PREP and RAMMET preprocessor programs also determine atmospheric stability according to the Turner method. As described earlier, the Turner method used to determine atmospheric stability is a completely objective method that relies, in part, on calcuation of solar elevation angle, sunrise, and sunset. The Turner method of stability computation is used in both the PREP and RAMMET preprocessor programs. It is also used in the STAR program that is used by the National Climatic Center to generate annual average meteorological information in the STAR format.

Because of this dependency of mixing height interpolation and stability calculation upon sunrise/sunset at a given location, the existence of periods with circumpolar sun conditions is very important for Prudhoe Bay.

Mixing Height Calculations for PREP

PREP (and RAMMET) were not designed to handle the situations where a meteorological station above the Arctic Circle experiences periods where the sun is circumpolar. In fact, PREP will terminate in the middle of a run when used with meteorological data from above the Arctic Circle.

There are two problems associated with PREP. First, the computational scheme physically will not work near the solstices since the program attempts to take the square root of a negative number. Second, given a correction to the square root, sunrise/sunset problem, the interpolation scheme for mixing heights near the solstices produces an interpolation that is a function of nonexistant sunrises and sunsets. Hence, the interpolation scheme will generate mixing heights of dubious validity near the solstices.

The principal driving force producing daily variations in the depth of the mixing layer at a given location is the diurnal cycle of daytime solar heating and nighttime radiational cooling. For the circumpolar sun situation, this diurnal cycle is eliminated, or greatly decreased in intensity. The result is that the PREP mixing height interpolation scheme that is based upon this normal diurnal heating/cooling cycle is probably not valid.

Modification to PREP

(1) Justification for Modification

It was necessary to determine a mixing height interpolation scheme for PREP for use near the solstices. The simple method of straight linear interpolation between successive afternoon mixing heights was chosen for use during the circumpolar sun periods. The normal PREP interpolation was used during the rest of the year.

This scheme is reasonable for several reasons:

- During the circumpolar sun periods, the normal driving force of mixing height variation, the diurnal heating/cooling cycle, is absent. Synoptic and mesoscale meteorological conditions then become the predominant driving force causing the mixing height to vary. It is not reasonably easy or practical to include synoptic and mesoscale meteorological factors in an interpolation scheme for mixing heights. Thus, in lieu of a theoretically more valid scheme, the simpler scheme should be used.

- Intuitively, straight interpolation is reasonable. Near the summer solstice, there is not the strong radiational cooling at night that normally produces low morning mixing heights. Near the winter solstice, radiational cooling is occurring constantly and there is no solar heating causing the afternoon mixing heights to rise compared to the morning value. Thus, any mixing height changes over a period will appear to change smoothly between successive values.

- The normal PREP interpolation scheme uses linear interpolation of mixing height values for most situations.

(2) Modification to PREP

The flow chart for the modification to PREP is given in Figure E-1. The actual FORTRAN code of the altered PREP program is given in Table E-1. New or changed lines of code are identified in the table. A schematic diagram of the mixing height interpolation scheme is given in Figure E-2.

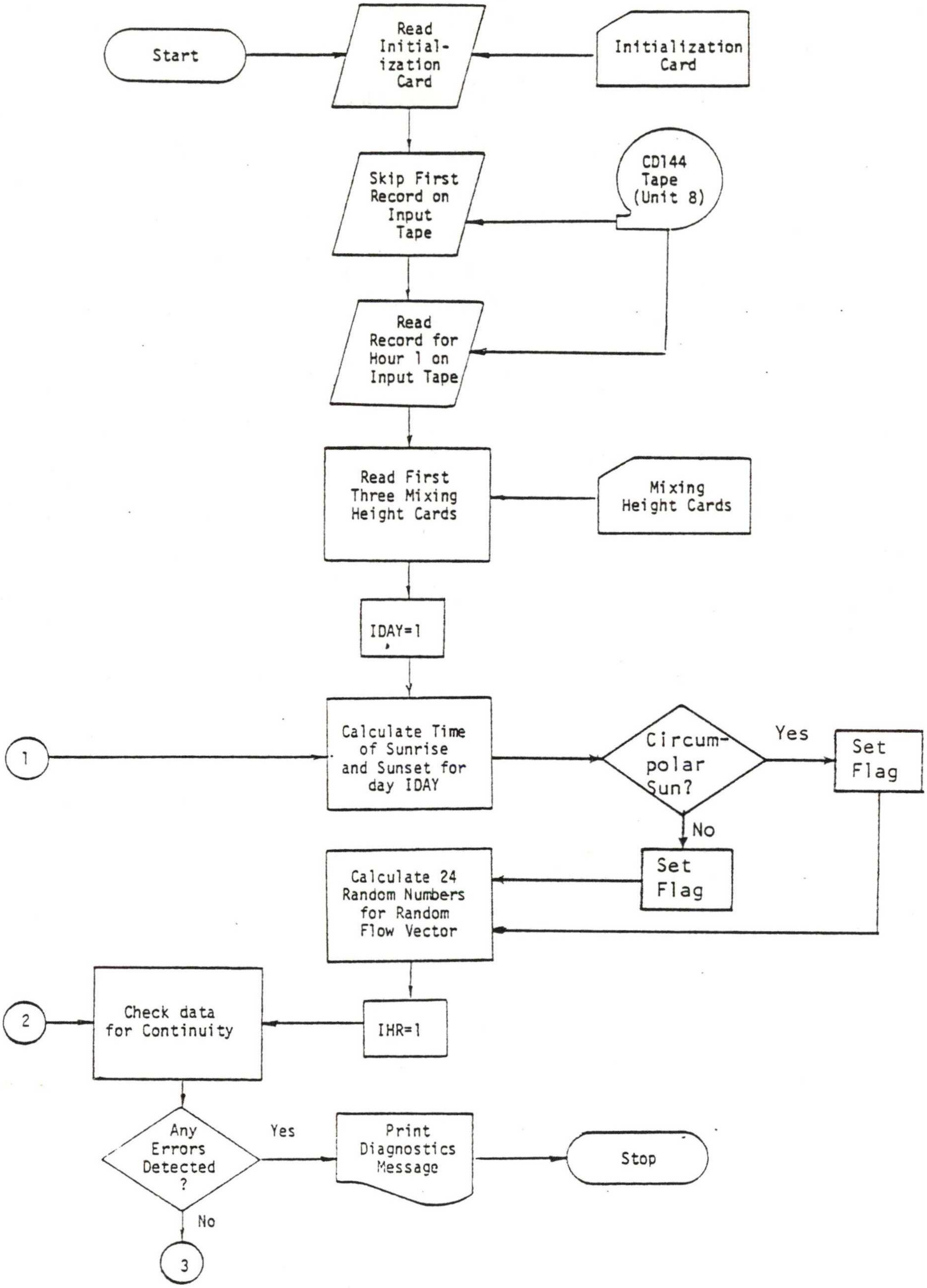

FIGURE E-1

MODIFIED PREPROCESSOR PROGRAM FLOW DIAGRAM

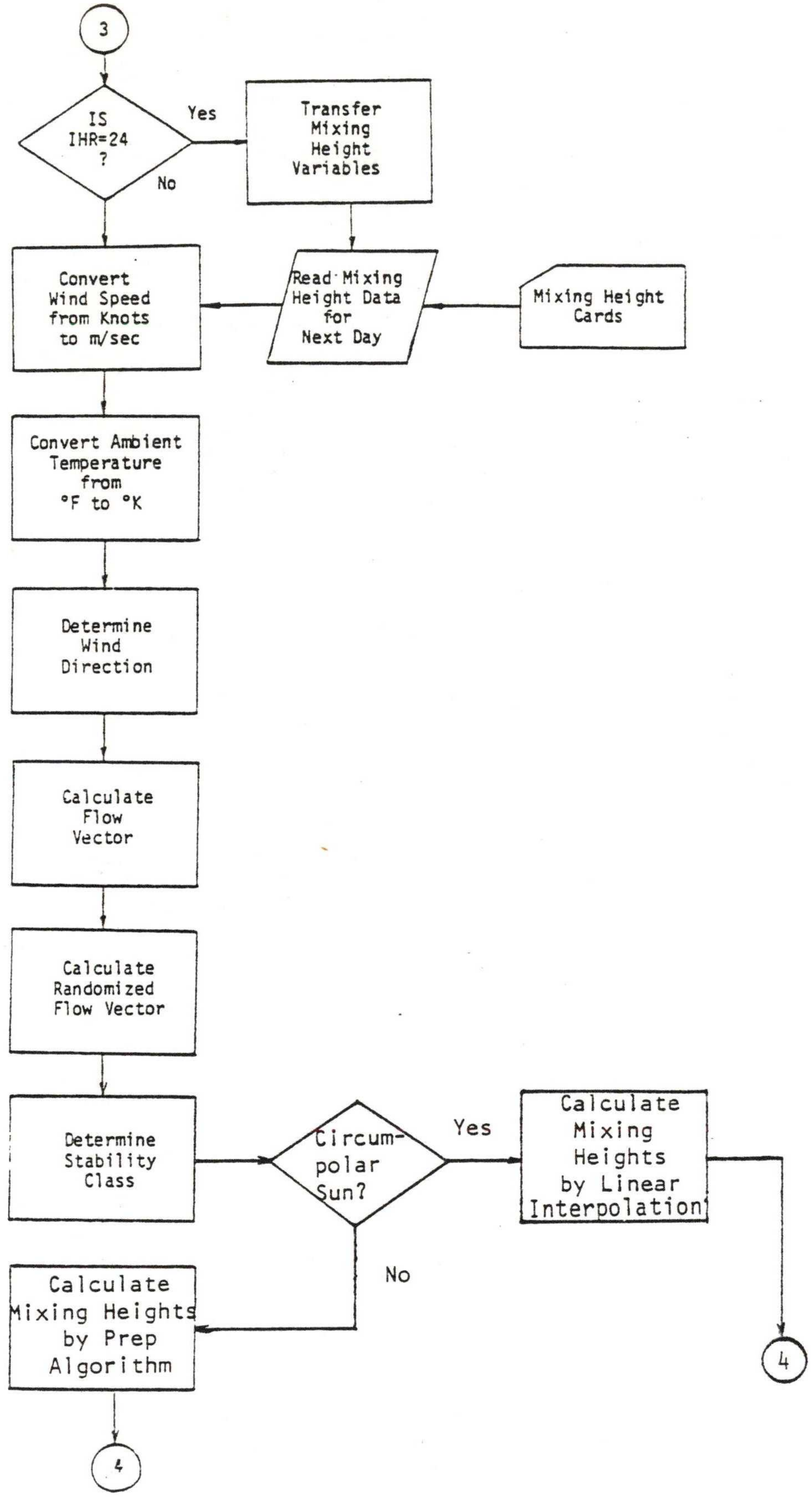

FIGURE E-1 (Continued)

MODIFIED PREPROCESSOR PROGRAM FLOW DIAGRAM

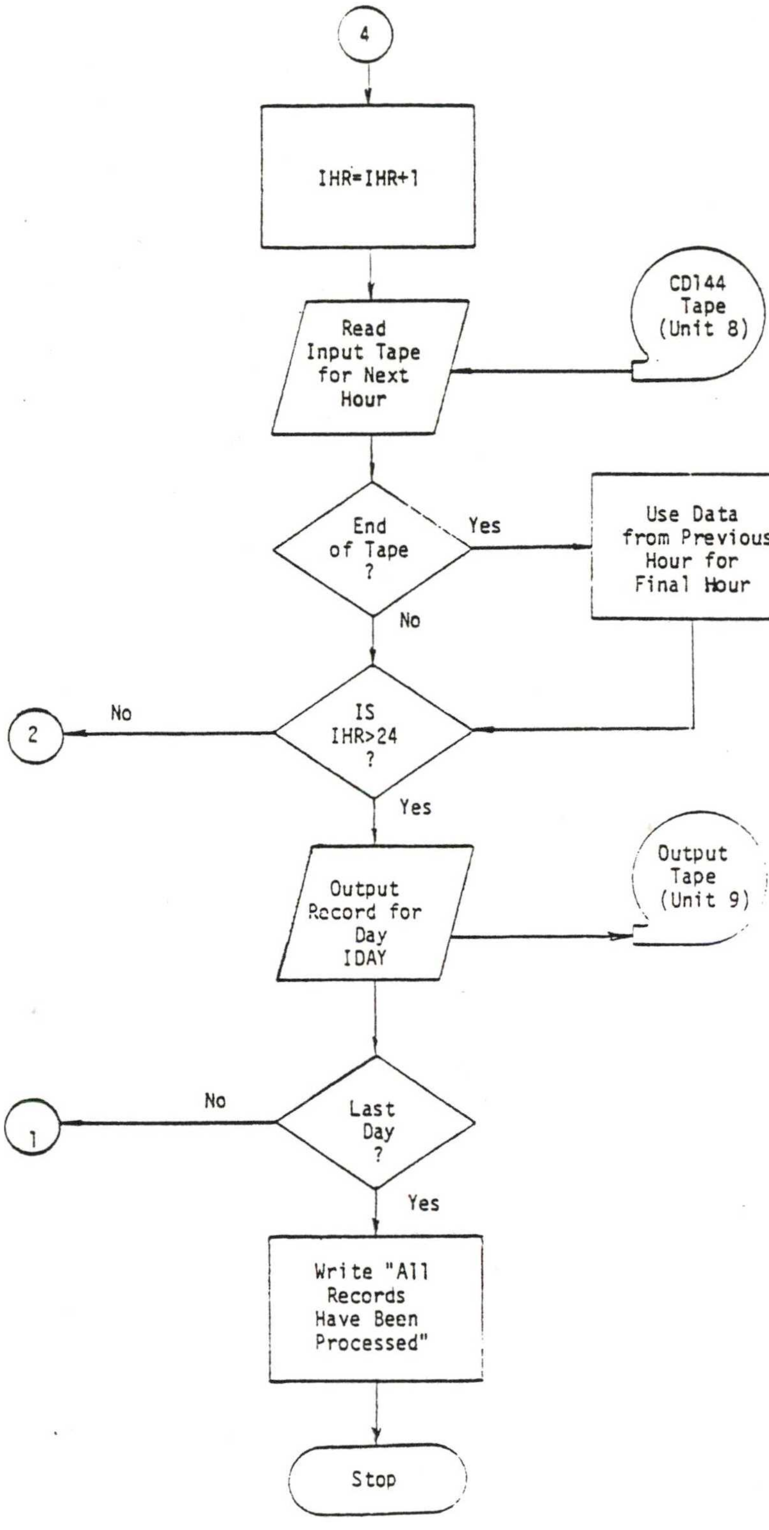

FIGURE E-1 (Continued)

MODIFIED PREPROCESSOR PROGRAM FLOW DIAGRAM

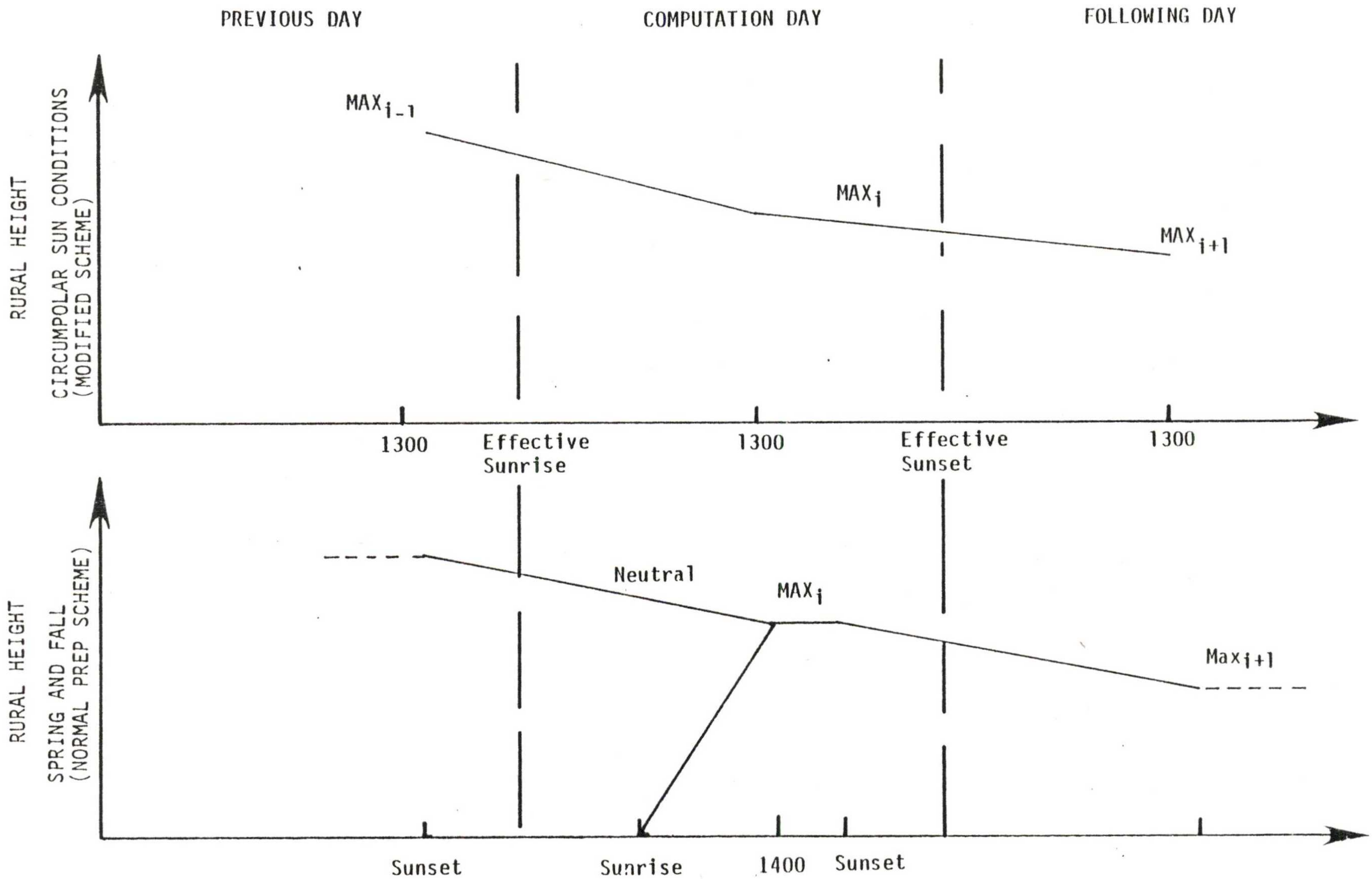

FIGURE E-2

DETERMINATION OF HOURLY MIXING HEIGHTS BY THE SINGLE SOURCE (CRSTER) MODEL PREPROCESSOR, AS MODIFIED BY RADIAN

In general, the changes to the PREP program were relatively simple. The following computational or logic steps were added to PREP.

(a) The interim trigonometric values used to calculate sunrise/sunset, and solar elevation angle, were limited to the range -1 to +1, which is the normal sine and cosine range. The correction was applied to the cosine of the half day length angle and also to the sine of the solar elevation angle. Without these trigonometric limits, the program attempts to take the square root of a negative number during certain circumpolar sun conditions and give extraneous values during other circumpolar sun conditions.

(b) Based upon the solar declination, a flag variable was assigned a value corresponding to circumpolar summer, circumpolar winter, and all other times.

(c) Sunrise and sunset were limited to 0000 hours and 2400 hours, respectively, at all times. During circumpolar summer, the sunrise and sunset were set to 0000 hours and 2400 hours respectively. This is necessary to prevent sunrise or sunset from being outside a given calender day.

(d) At the beginning of mixing height calculations, the flag variable was checked. For circumpolar sun conditions in summer and winter, the program branched to straight interpolation for mixing heights. For all other times, the program continued through the normal PREP interpolation scheme.

(3) Significant Aspects of PREP Modifications

There are several important consequences of the normal and modified PREP mixing height interpolation scheme.

(a) Under all stability conditions, PREP continues the afternoon maximum mixing height from 1400 hours until sunset. For the period just before the sun becomes circumpolar and just finishes being circumpolar in the summer, the afternoon maximum mixing height is continued straight for 9 or 10 hours. For the above two cases, the sunset is near 2400 hours and so the same mixing height is maintained from 1400 to 2200 or 2300 hours. In certain circumstances, this may not be a reasonable assumption. However, to correct this deficiency would entail added modification to PREP beyond what was required. Radian felt this was not a significant point and so did not further modify PREP.

(b) Depending upon the location of a meteorological observation station within its time zone, sunrise or sunset may potentially be on the previous calendar day or the following one. For example, sunset may be at 0020 hours the next day. On a different day, sunrise may be at 2348 hours. The computation scheme will not work properly when this happens since, for example, on the day with sunrise at 2348 hours, sunset will probably be near 2300 hours and so sunrise will be after sunset, an impossible circumstance computationally. This is so because the program cannot know that these values are on two different days. This problem is alleviated by limiting sunrise/sunset to 0000 hours and 2400 hours, respectively. On a few days, this will produce times of sunrises or sunsets slightly different than actual times. This problem is minor, however, and so was ignored.

Source of Mixing Height Data

Twice daily mixing heights for Barter Island for 1964 were used in the PSD analysis. These mixing height data were provided to Radian by SOHIO. The original source of the data was the National Climatic Center which applied the Holzworth Method (Turner, 1961) to 1964 Barter Island upper air soundings to produce twice daily mixing heights.

Turner's Method and Sunrise/Sunset

Turner's Method requires that the times of sunrise and sunset and solar elevation angles be calculated. In the PREP, RAMMET and STAR programs, if the program correctly handles all sunrise/sunset and solar elevation angle calculations, the program correctly calculates stabilities using Turner's Method. This applies whether the sun is circumpolar or not. This is not saying, however, that Turner's method is completely valid for use in the circumpolar sun region. This point has already been discussed earlier.

Radian modified its STAR program to correctly calculate effective circumpolar sunrises and sunsets according to the same methodology described for modifying PREP. The equations used in both programs are identical and so a listing of the change was felt not to be necessary since the modification to PREP is described in this appendix and is listed in Table E-1.

TABLE E-1

CRSTER PREPOSSESSOR WITH MODIFICATIONS

```
00100    C***CRSTER-PREPROCESSOR- WRITTEN BY JOAN HRENKO NOVAK                    MET00010
00100    C*** BASED ON METHODS SUGGESTED BY TURNER , ZIMMERMAN, AND IRWIN.        MET00020
00100    C*** VERSION 77166                                                       MET00030
00100    C***THE PROGRAM ASSUMES THERE IS NO MISSING DATA ON THE MET. TAPE.       MET00040
00100    C***IF MISSING DATA IS DETECTED, THE LOCATION OF THE MISSING DATA IS     MET00050
00100    C***PRINTED. MISSING DATA MUST BE FILLED IN BEFORE PROCEEDING .          MET00060
00100    C                                                                           *NEW
00100    C    PREP1***PATCH TO HANDLE MIXING HEIGHTS FOR SOHIO-ALASKA.  REGULAR CRSTER   *NEW
00100    C    PREPPROCESSOR SCHEME USED FOR SPRING AND FALL MIXING HEIGHTS.  STRAIGHT    *NEW
00100    C    INTERPOLATION BETWEEN AFTERNOON MISING HEIGHTS USED FOR CIRCUMPOLAR SUN    *NEW
```

```
00100      C    WHERE IDEC= 2 OR 3.  URBAN AND RURAL MIXING HEIGHTS ARE SET EQUAL TO EACH    *NEW
00100      C    OTHER FOR WINTER AND SUMMER.  AFTERNOON MIXING HEIGHTS ASSUMED TO BE VALID  *NEW
00100      C    FOR 1300L.  SUNRISE AND SUNSET FOR SUMMER SET TO 00L AND 24L RESPECTIVELY.  *NEW
00100      C    PATCH BY HWB, AUG 1979                                                       *NEW
00100      C                                                                                 *NEW
00101            DIMENSION LSTAB(12,7), IDFAC(12,2), ANGL(3), ICEIL(3), IDG(3), IDIMET00070
00101           1G(11)                                                               MET00080
00103            DIMENSION KST(24), SPEED(24), TEMP(24), AFV(24), FVR(24), HLH(2,24MET00090
00103           1), RAND(24)                                                         MET00100
00104            DATA IDIG /'0','1','2','3','4','5','6','7','8','9','-'/             MET00110
00106            DATA IREC /1/ ,IMO /1/ ,ANGL /60.,35.,15./ ,CONST /57.29578/        MET00120
00113            DATA IDFAC /0,31,59,90,120,151,181,212,243,273,304,334,0,31,60,91,MET00130
00113           1121,152,182,213,244,274,305,335/                                    MET00140
00115            DATA LSTAB /7,7,7,6,6,6,5,5,5,5,4,4,6,6,6,5,5,5,4,4,4,4,4,4,4,4,4,4,MET00150
00115           14,4,4,4,4,4,4,4,4,3,3,3,4,4,4,4,4,4,4,4,4,2,2,2,3,3,3,3,3,3,4,4,4,MET00160
00115           21,2,2,2,2,2,2,3,3,3,3,4,1,1,1,1,1,2,2,2,2,3,3,3/                    MET00170
00115      C***    UNIT 8 = SURFACE DATA                                             MET00180
00115      C***    UNIT 9 = OUTPUT FILE                                              MET00190
00115      C***    UNIT 5 = UPPER AIR DATA IN CARD FORMAT                            MET00200
00117            IN=5                                                                MET00210
00120            IO=6                                                                MET00220
00121            IFLAG=0                                                             MET00230
00121      C***READ CARD TO INITIALIZE MET TAPE ID,YEAR,LATITUDE,LONGITUDE,          MET00240
00121      C*** TIME ZONE ,NO. OF DAYS IN YEAR, INITIAL RANDOM NUMBER.               MET00250
00121      C***RAND(24) IS THE INITIAL RANDOM NO. USED TO GENERATE THE SEQUENCE OF  MET00260
00121      C***NUMBERS FOR THE RAMDOMIZED FLOW VECTOR. IF THE SAME NO. IS USED IN   MET00270
00121      C***DIFFERENT EXECUTIONS OF THE PREPROCESSOR, THE SAME SET OF RANDOM NOSMET00280
00121      C***WILL BE GENERATED. ANY ODD NUMBER GREATER THAN 3 DIGITS CAN BE USED MET00290
00121      C***AS THE SEED. THIS SEED IS MULTIPLIED BY 10000 INTERNALLY.            MET00300
00121      C***ZONE IS GMT-LST.                                                      MET00310
00122            READ (IN,400) IDC,IYRC,ALAT,ALONG,ZONE,NDAYS,RAND(24)               MET00320
00133            WRITE (IO,410) IDC,IYRC,ALAT,ALONG,ZONE,NDAYS,RAND(24)              MET00330
00144            DUM=ALAT/CONST                                                      MET00340
00145            SINLAT=SIN(DUM)                                                     MET00350
00146            COSLAT=COS(DUM)                                                     MET00360
00147            DUM=ALONG/15.-ZONE                                                  MET00370
00150            TEMPZ=15.*ZONE-ALONG                                                MET00380
00150      C***RESET SUBSRIPT IF LEAP YEAR                                           MET00390
00151            LYS=1                                                               MET00400
00152            IF (NDAYS.EQ.366) LYS=2                                             MET00410
00152      C***READ MET DATA                                                         MET00420
00152      C***THIS READ ASSUMES AN INPUT TAPE WITH HOURLY DATA FROM THE            MET00430
00152      C***NATIONAL CLIMATIC CENTER, ASHVILLE, NC. IN THEIR STANDARD            MET00440
```

```
00152   C***HOURLY CARD FORMAT.                                                         MET00450
00152   C***SKIP 00 HOUR OF MET DATA.                                                   MET00460
00154         READ (8,420) ID,IYEAR,IMONTH,IDAY,IHOUR,ICEIL,IDIR,ISPEED,ITEMP,ICMET00470
00154        1OVER                                                                      MET00480
00173         LWD=IDIR                                                                  MET00490
00173   C***BEGIN PROCESSING WITH HOUR 01                                               MET00500
00174         READ (8,420) ID,IYEAR,IMONTH,IDAY,IHOUR,ICEIL,IDIR,ISPEED,ITEMP,ICMET00510
00174        1OVER                                                                      MET00520
00174   C***MIXING HEIGHT VALUES ARE DETERMINED TWICE A DAY FROM RADIOSONDE DATAMET00530
00174   C***USING THE PROCEDURES OF HOLZWORTH.                                          MET00540
00174   C***READ PRIOR DAYS MIXING HEIGHT VALUES                                        MET00550
00213         READ (IN,430) XMNM1,XAFM1                                                 MET00560
00213   C***PRESENT DAY                                                                 MET00570
00217         READ (IN,440) IDM,IYM,XMN,XAF                                             MET00580
00217   C***WRITE IDENTIFYING INFORMATION ON OUTPUT FILE                                MET00590
00225         WRITE (9) ID,IYEAR,IDM,IYM                                                MET00600
00233         WRITE (IO,450) IYEAR,ID,IYM,IDM                                           MET00610
00233   C*** READ NEXT DAY'S MIXING HEIGHT VALUES                                       MET00620
00241         READ (IN,430) XMNP1,XAFP1                                                 MET00630
00241   C***START DAY LOOP.                                                             MET00640
00245         DO 380 IDY=1,NDAYS                                                        MET00650
00245   C***CALCULATE THE DAY NO AND THE TIME OF SUNRISE AND SUNSET                     MET00660
00250         DAY1=IDAY+IDFAC(IMONTH,LYS)                                               MET00670
00250   C***CONSTANT 0.0172028=360./365.242*57.29578                                    MET00680
00250   C***DETERMINE THE ANGULAR(RADIANS) FRACTION OF A YEAR FOR THIS DATE.            MET00690
00251         DAYNO=(DAY1-1.0)*0.0172028                                                MET00700
00252         TDAYNO=2.*DAYNO                                                           MET00710
00253         SIND=SIN(DAYNO)                                                           MET00720
00254         COSD=COS(DAYNO)                                                           MET00730
00255         SINTD=SIN(TDAYNO)                                                         MET00740
00256         COSTD=COS(TDAYNO)                                                         MET00750
00256   C***ACCOUNT FOR ELLIPTICITY OF EARTH'S ORBIT.                                   MET00760
00257         SIGMA=279.9348+(DAYNO*CONST)+1.914827*SIND-0.079525*COSD+0.019938*MET00770
00257        1SINTD-0.00162*COSTD                                                       MET00780
00257   C***CONSTANT 0.39785=SIN(.4091720193=23.44383/57.29578)                         MET00790
00257   C***FIND THE SINE OF THE SOLAR DECLINATION.                                     MET00800
00260         DSIN=0.39785*SIN(SIGMA/CONST)                                             MET00810
00261         DCOS=SQRT(1.0-DSIN*DSIN)                                                  MET00820
00261   C                                                                                  *NEW
00261   C     CHECK FOR CIRCUMPOLAR SUN AND SET FLAG.                                      *NEW
00261   C     CRITICAL ANGLE FOR CIRCUMPOLAR SUN IS (90 - LAT).  THE TRIG IDENTITY         *NEW
00261   C     COS(90-LAT)=SIN(LAT) IS USED.  WHEN THIS ANGLE IS LESS THAN THE ABSOLUTE     *NEW
00261   C     VALUE OF THE SOLAR DECLINATION, THE SUN IS CIRCUMPOLAR.  WHEN DSIN.GT.0,     *NEW
```

```
00261   C    DECLINATION IS POSITIVE AND IT IS SUMMER.  WHEN DSIN.LT.0, IT IS WINTER.        *NEW
00261   C    ****IDEC**** IS A FLAG.  WHEN: IDEC=1, SUN IS NOT CIRCUMPOLAR.  IDEC=2, THE   *NEW
00261   C    SUN IS CIRCUMPOLAR-SUMMER, IDEC=3, THE SUN IS CIRCUMPOLAR-WINTER.            *NEW
00262            IDEC=1                                                                   *NEW
00263            IF (SINLAT.LT.DCOS) GO TO 7                                              *NEW
00265            IF (DSIN) 5,6,6                                                          *NEW
00270   5        IDEC=3                                                                   *NEW
00271            GO TO 7                                                                  *NEW
00272   6        IDEC=2                                                                   *NEW
00273   7        CONTINUE                                                                 *NEW
00273   C                                                                                 *NEW
00273   C***DETERMINE TIME(HRS) OF MERIDIAN PASSAGE                               MET00830
00274            AMM=12.0+0.12357*SIND-0.004289*COSD+0.153809*SINTD+0.060783*COSTD MET00840
00275            HCOS=(-SINLAT*DSIN)/(COSLAT*DCOS)                                MET00850
00275   C                                                                                 *NEW
00276            IF (HCOS.GT.1.0) HCOS=1.0                                                *NEW
00300            IF (HCOS.LT.-1.0) HCOS=-1.0                                              *NEW
00300   C                                                                                 *NEW
00300   C***DETERMINE SOLAR HOUR ANGLE OF SUNRISE-SUNSET.                         MET00860
00302            H2=(ATAN2(SQRT(1.-HCOS*HCOS),HCOS)/15.0)*CONST                   MET00870
00302   C***TIME OF SUNRISE(TSR) AND TIME OF SUNSET(TSS) ARE EXPRESSED IN         MET00880
00302   C***LOCAL STANDARD TIME SINCE THE ZONE CORRECTION HAS ALREADY BEEN MADE.MET00890
00302   C***OTHERWISE THEY WOULD BE IN GREENWICH MEAN TIME.                       MET00900
00303            TSR=AMM-H2+DUM                                                   MET00910
00304            TSS=AMM+H2+DUM                                                   MET00920
00304   C                                                                                 *NEW
00304   C    ENSURE THAT SUNRISE AND SUNSET DO NOT EXCEED THE CALENDAR DAY.               *NEW
00305            IF (TSR.LT.0.0) TSR = 0.0                                                *NEW
00307            IF (TSS.GT.24.0) TSS = 24.0                                              *NEW
00311            IF (IDEC.NE.2) GO TO 8                                                   *NEW
00313            TSR = 0.0                                                                *NEW
00314            TSS = 24.0                                                               *NEW
00315   8        CONTINUE                                                                 *NEW
00315   C                                                                                 *NEW
00316            RAND(1)=RAND(24)*10000.                                          MET00930
00316   C***THIS CALL TO THE UNIVAC RANDOM NO. GENERATOR PROVIDES 24 UNIFORMLY    MET00940
00316   C***DISTRIBUTED NUMBERS BETWEEN 0 AND 1.                                  MET00950
00316   C***IF THIS ROUTINE IS NOT RUN ON A UNIVAC MACHINE, THE RANDOM NO.        MET00960
00316   C***GENERATOR FOR THE USER'S SYSTEM MAY BE SUBSTITUTED.                   MET00970
00317            CALL RANDU (RAND,24)                                             MET00980
00317   C***START HOUR LOOP                                                       MET00990
00320            DO 370 KHR=1,24                                                  MET01000
00323            KHRC=KHR                                                         MET01010
```

```
00323   C***INITIALIZE STABILITY BEFORE IT IS CALCULATED                 MET01020
00324         KST(KHR)=0                                                 MET01030
00325         IF (KHR.EQ.24) GO TO 70                                    MET01040
00325   C***CHECK DATA FOR CORRECTNESS + CONTINUITY                      MET01050
00325   C***CHECK STATION NUMBER.                                        MET01060
00327         IF (ID.EQ.IDC) GO TO 10                                    MET01070
00331         WRITE (IO,460) IREC,ID,IDC                                 MET01080
00336         WRITE (IO,510)                                             MET01090
00340         CALL EXIT                                                  MET01100
00340   C***CHECK YEAR.                                                  MET01110
00341   10    IF (IYEAR.EQ.IYRC) GO TO 20                                MET01120
00343         WRITE (IO,470) IYEAR,IYRC,IREC                             MET01130
00350         WRITE (IO,510)                                             MET01140
00352         CALL EXIT                                                  MET01150
00352   C***CHECK MONTH                                                  MET01160
00353   20    IF (IMONTH.EQ.IMO) GO TO 40                                MET01170
00355         IF (IMONTH.EQ.(IMO+1)) GO TO 30                            MET01180
00357         WRITE (IO,480) IMONTH,IMO,IREC                             MET01190
00357   C***                                                             MET01200
00364         WRITE (IO,510)                                             MET01210
00366         CALL EXIT                                                  MET01220
00367   30    IMO=IMONTH                                                 MET01230
00367   C***CHECK DAY                                                    MET01240
00370   40    IF (IFIX(DAY1).EQ.IDY) GO TO 50                            MET01250
00372         WRITE (IO,490) DAY1,IDY,IREC                               MET01260
00377         WRITE (IO,510)                                             MET01270
00401         CALL EXIT                                                  MET01280
00401   C***CHECK HOUR                                                   MET01290
00402   50    IF (IHOUR.EQ.KHRC) GO TO 60                                MET01300
00404         WRITE (IO,500) IHOUR,KHR,IREC                              MET01310
00411         WRITE (IO,510)                                             MET01320
00413         GO TO 370                                                  MET01330
00414   60    WRITE (IO,520) KHR,IREC,IHOUR                              MET01340
00421         CALL EXIT                                                  MET01350
00422   70    IF (IHOUR.NE.0) GO TO 60                                   MET01360
00424         KHRC=IHOUR                                                 MET01370
00424   C***UPDATE MIXING HEIGHTS- STARTING NEW DAY.                     MET01380
00425         XMNM1=XMN                                                  MET01390
00426         XAFM1=XAF                                                  MET01400
00427         XMN=XMNP1                                                  MET01410
00430         XAF=XAFP1                                                  MET01420
00430   C***READ NEXT DAYS MIXING HEIGHTS.                               MET01430
00431         READ (IN,430,END=80) XMNP1,XAFP1                           MET01440
```

```
00435        80    DO 90 JK=1,11
00440              IF (ICOVER.EQ.IDIG(JK)) GO TO 100
00442        90    CONTINUE
00444              JK=11
00445              WRITE (IO,530) ICOVER
00450        100   ISKY=JK-1
00451              IF (ICEIL(1).NE.IDIG(11)) GO TO 110
00453              IDG(1)=9
00454              IDG(2)=9
00455              IDG(3)=8
00456              GO TO 150
00457        110   DO 140 JI=1,3
00462              DO 120 JK=1,10
00465              IF (ICEIL(JI).EQ.IDIG(JK)) GO TO 130
00467        120   CONTINUE
00471        130   IDG(JI)=JK-1
00472        140   CONTINUE
00474        150   IROOF=IDG(1)*100+IDG(2)*10+IDG(3)
00474        C***IROOF IS CEILING HEIGHT IN HUNDREDS OF FEET.
00474        C***CONVERT TEMP FROM FAHRENHEIT TO KELVIN
00475              TEMP(KHR)=0.5556*(ITEMP-32.)+273.15
00475        C***CONVERT WIND SPEED FROM KNOTS TO METERS/SEC
00476              S=ISPEED*0.51444
00476        C***WIND SPEED IS SET TO 1 METER/SEC
00477              IF (S.LT.1.0) S=1.0
00501              SPEED(KHR)=S
00501        C***CHECK FOR CALMS
00502              IF (IDIR.EQ.0) GO TO 160
00502        C***WIND DIRECTION IS ASSUMED TO BE THE SAME AS FOR THE LAST HOUR
00502        C***IF THE WIND DIRECTION IS REPORTED AS @CALM@.
00504              LWD=IDIR
00505              GO TO 170
00506        160   IDIR=LWD
00507        170   XDIR=IDIR*10.
00507        C***CALCULATE FLOW VECTOR AND RANDOM FLOW VECTOR
00510              IF (XDIR.GT.180.) GO TO 180
00512              FV=XDIR+180.
00513              GO TO 190
00514        180   FV=XDIR-180.
00515        190   AFV(KHR)=FV
00516              IRAND=RAND(KHR)*10.
00516        C***IRAND IS SINGLE DIGIT FROM 0 TO 9.
00517              FVP(KHR)=FV+IRAND-4.0
```

```
00520        IF (FVR(KHR).GT.360.) FVR(KHR)=FVR(KHR)-360.                          MET01880
00520   C***DETERMINE RADIATION INDEX.                                             MET01890
00522        IF (ISKY.EQ.10.AND.IROOF.LT.70) GO TO 200                             MET01900
00524        IF (IHOUR.GT.TSR.AND.IHOUR.LT.TSS) GO TO 210                          MET01910
00526        IRADX=2                                                               MET01920
00527        IF (ISKY.LE.4) IRADX=1                                                MET01930
00531        GO TO 280                                                             MET01940
00532   200  IRADX=3                                                               MET01950
00533        GO TO 280                                                             MET01960
00533   C***DETERMINE THE ANGLE OF ELEVATION                                       MET01970
00533   C***DETERMINE SOLAR HOUR ANGLE(RADIANS)                                    MET01980
00534   210  HI=(15.*(KHRC-AMM)+TEMPZ)/CONST                                       MET01990
00535        ALFSN=SINLAT*DSIN+DCOS*COSLAT*COS(HI)                                 MET02000
00535   C                                                                               *NEW
00536        IF (ALFSN.GT.1.0) ALFSN=1.0                                                *NEW
00540        IF (ALFSN.LT.-1.0) ALFSN=-1.0                                              *NEW
00540   C                                                                               *NEW
00540   C***DETERMINE SOLAR ELEVATION ANGLE(DEG).                                  MET02010
00542        ALF=ATAN2(ALFSN,SQRT(1.-ALFSN*ALFSN))*CONST                           MET02020
00543        DO 220 I=1,3                                                          MET02030
00546   220  IF (ALF.GT.ANGL(I)) GO TO 230                                         MET02040
00551        I=4                                                                   MET02050
00552   230  ICN=5-I                                                               MET02060
00553        IF (ISKY.GT.5) GO TO 240                                              MET02070
00555        IRADX=ICN+3                                                           MET02080
00556        GO TO 280                                                             MET02090
00557   240  IRADX=ICN-1                                                           MET02100
00560        IF (IROOF.LT.70) GO TO 250                                            MET02110
00562        IF (IROOF.LT.160) GO TO 260                                           MET02120
00564        IF (ISKY.EQ.10) GO TO 270                                             MET02130
00566        IRADX=ICN                                                             MET02140
00567        GO TO 270                                                             MET02150
00570   250  IRADX=ICN-2                                                           MET02160
00571        GO TO 270                                                             MET02170
00572   260  IF (ISKY.EQ.10) IRADX=IRADX-1                                         MET02180
00574   270  IF (IRADX.LT.1) IRADX=1                                               MET02190
00576        IRADX=IRADX+3                                                         MET02200
00577   280  IND=ISPEED                                                            MET02210
00600        IF (ISPEED.GT.12) IND=12                                              MET02220
00602        IF (ISPEED.LE.1) IND=1                                                MET02230
00602   C***DETERMINE STABILITY.                                                   MET02240
00604        KST(KHR)=LSTAB(IND,IRADX)                                             MET02250
00604   C***DO NOT ALLOW STABILITY TO VARY RAPIDLY                                 MET02260
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00605      IF (IDY.EQ.1.AND.KHR.EQ.1) LST=KST(KHR)                            MET02270
00607      IF ((KST(KHR)-LST).GT.1) KST(KHR)=LST+1                            MET02280
00611      IF ((LST-KST(KHR)).GT.1) KST(KHR)=LST-1                            MET02290
00613      LST=KST(KHR)                                                       MET02300
00614      IF (KST(KHR).LT.1) WRITE (IO,540) KST(KHR),IND,IRADX,IREC          MET02310
00614 C***CALCULATE MIXING HEIGHT                                             MET02320
00623      IHR=KHRC                                                           MET02330
00624      XHR=IHR                                                            MET02340
00624 C                                                                           *NEW
00624 C    CHECK FOR CIRCUMPOLAR SUN AND BRANCH TO PROPER MIXING HEIGHT SCHEME.   *NEW
00625      IF (IDEC.EQ.2.OR. IDEC.EQ.3) GO TO 355                                 *NEW
00625 C                                                                           *NEW
00627      IF (IHR.GT.14.AND.XHR.LE.TSS) GO TO 300                            MET02350
00631      IND=2                                                              MET02360
00632      IF (XHR.LE.TSS) GO TO 310                                          MET02370
00634      IF (KST(KHR).EQ.4) GO TO 290                                       MET02380
00636      HLH(2,KHR)=XAF+(XMNP1-XAF)*((XHR-TSS)/(24.-TSS))                   MET02390
00637      IND=1                                                              MET02400
00640  290 HLH(IND,KHR)=XAF+(XAFP1-XAF)*((XHR-TSS)/(38.-TSS))                 MET02410
00641      IF (IND.EQ.2) HLH(1,KHR)=HLH(2,KHR)                                MET02420
00643      GO TO 360                                                          MET02430
00644  300 HLH(1,KHR)=XAF                                                     MET02440
00645      HLH(2,KHR)=XAF                                                     MET02450
00646      GO TO 360                                                          MET02460
00647  310 IF (XHR.GT.TSR) GO TO 330                                          MET02470
00651      KSTSP=KST(KHR)                                                     MET02480
00652      IF (KST(KHR).EQ.4) GO TO 320                                       MET02490
00654      HLH(2,KHR)=XMN                                                     MET02500
00655      IND=1                                                              MET02510
00656  320 HLH(IND,KHR)=XAFM1+(XAF-XAFM1)*((24.-TSS+XHR)/(24.-TSS+14.))       MET02520
00657      IF (IND.EQ.2) HLH(1,KHR)=HLH(2,KHR)                                MET02530
00661      GO TO 360                                                          MET02540
00662  330 IF (KSTSP.EQ.4) GO TO 350                                          MET02550
00664      HLH(2,KHR)=XMN+(XAF-XMN)*((XHR-TSR)/(14.-TSR))                     MET02560
00665      HLH(1,KHR)=XAF*(XHR-TSR)/(14.-TSR)                                 MET02570
00666      GO TO 360                                                          MET02580
00667  340 IFLAG=1                                                            MET02590
00670      IHOUR=0                                                            MET02600
00671      GO TO 370                                                          MET02610
00672  350 HLH(1,KHR)=XAFM1+(XAF-XAFM1)*((24.-TSS+XHR)/(24.-TSS+14.))         MET02620
00673      HLH(2,KHR)=HLH(1,KHR)                                              MET02630
00673 C                                                                           *NEW
00673 C    MIXING HEIGHT INTERPOLATION FOR CIRCUMPOLAR SUN.                       *NEW
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00674    355   IF (KHR.EQ.24) GO TO 356                                                  *NEW
00676          IF (KHR.GT.13) GO TO 357                                                  *NEW
00700    356   HLH(1,KHR) = XAFM1 + (XAF-XAFM1)*(11 + KHRC)/24                           *NEW
00701          HLH(2,KHR) = HLH(1,KHR)                                                   *NEW
00702          GO TO 358                                                                 *NEW
00703    357   HLH(1,KHR) = XAF + (XAFP1 - XAF)*(KHR - 13)/24                            *NEW
00704          HLH(2,KHR) = HLH(1,KHR)                                                   *NEW
00705    358   CONTINUE                                                                  *NEW
00705    C                                                                               *NEW
00705    C***READ NEXT HOUR'S MET DATA                                            MET02640
00706    360   IF (IFLAG.EQ.1) GO TO 390                                          MET02650
00706    C***STORE CORRECT MONTH AND DAY FOR DAILY PRINTOUT, SINCE 24TH HOUR LABEMET02660
00710          IF(KHR.NE.23) GO TO 365                                            MET02670
00712          LMON=IMONTH                                                        MET02680
00713          LDAY=IDAY                                                          MET02690
00714    365   READ (8,420,END=340) ID,IYEAR,IMONTH,IDAY,IHOUR,ICFIL,IDIR,ISPEED,MET02700
00714         1ITEMP,ICOVER                                                       MET02710
00733          IREC=IREC+1                                                        MET02720
00733    C***END OF HOUR LOOP.                                                    MET02730
00734    370   CONTINUE                                                           MET02740
00734    C***WRITE DAYS CALCULATION ON TO FILE                                    MET02750
00734    C***EACH ARRAY CONTAINS THE COMPLETE INFORMATION FOR ONE DAY ORDERED     MET02760
00734    C***SEQUENTIALLY FROM HOUR 01 THRU 24                                    MET02770
00736          WRITE (9) IYEAR,LMON,DAY1,KST,SPEED,TEMP,AFV,FVR,HLH               MET02780
00773          WRITE (IO,550) IYEAR,LMON,LDAY,DAY1,TSR,TSS                        MET02790
01003          WRITE (IO,560) KST                                                 MET02800
01011          WRITE (IO,570) SPEED,TEMP,AFV,FVR,((HLH(I,J),J=1,24),I=1,2)        MET02810
01011    C***END OF DAY LOOP.                                                     MET02820
01042    380   CONTINUE                                                           MET02830
01044    390   WRITE (9) IYEAR,LMON,DAY1,KST,SPEED,TEMP,AFV,FVR,HLH               MET02840
01101          WRITE (IO,550) IYEAR,LMON,LDAY,DAY1,TSR,TSS                        MET02850
01111          WRITE (IO,560) KST                                                 MET02860
01117          WRITE (IO,570) SPEED,TEMP,AFV,FVR,((HLH(I,J),J=1,24),I=1,2)        MET02870
01150          WRITE (IO,580)                                                     MET02880
01152          CALL EXIT                                                          MET02890
01152    C                                                                        MET02900
01153    400   FORMAT (I5,I2,1X,2F10.1,F2.0,I4,F10.0)                             MET02910
01154    410   FORMAT(' STATION NUMBER=',I5,5X,'YEAR OF DATA=',I2/1X,             MET02920
01154         *'LATITUDE=',F10.1,'  LONGITUDE=',F10.1,'  ZONE=',F4.0/1X,          MET02930
01154         *'NUMBER OF DAYS IN YEAR=',I3,'  RANDOM SEED=',F10.0)               MET02940
01155    420   FORMAT (I5,4I2,3A1,22X,2I2,4X,I3,29X,A1)                           MET02950
01155    C                                                                               *NEW
01156    430   FORMAT (12X,F5.0,6X,F5.0)                                                 *NEW
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01157   440   FORMAT (I5,I2,5X,F5.0,6X,F5.0)                                                    *NEW
01157         C                                                                                  *NEW
01160   450   FORMAT (1X,'19',I2,' SURFACE DATA AT STATION ',I5,10X,'19',I2,' MIMET02980**-2
01160         1XING HEIGHT DATA AT STATION ',I5)                                            METC2990
01161   460   FORMAT (' ID DOES NOT MATCH IN RECORD = ',I4,'  ID ON TAPE IS ',I5MET03000
01161         *,' ID REQUESTED IS ',I5)                                                     MET03010
01162   470   FORMAT (' YEAR IS',I3,' INSTEAD OF ',I2,' IREC=',I4)                         MET03020
01163   480   FORMAT (' MONTH ',I2,' DOES NOT AGREE WITH LOOP ',I2,' IREC=',I4) MET03030
01164   490   FORMAT (' DAY ',I2,' DOES NOT AGREE WITH LOOP ',I2,' IREC=',I4)   MET03040
01165   500   FORMAT (' HOUR ',I2,' DOES NOT AGREE WITH LOOP ',I2,' IREC=',I4)  MET03050
01166   510   FORMAT (' *****DATA IS MISSING. PLEASE CORRECT INPUT FILE*****')  MET03060
01167   520   FORMAT (' ERROR: MISSING HOUR LOOP VALUE= ',I3,' WHILE VALUE ',' ONMET03070
01167         1 RECORD ',I7,' IS = ',I3)                                                    MET03080
01170   530   FORMAT (' THE CHARACTER ',A1,' IS NOT ALLOWABLE.',' CLOUD COVER DEMET03090
01170         1FAULTS TO 10.')                                                              MET03100
01171   540   FORMAT (' STABILITY=',4I4)                                                    MET03110
01172   550   FORMAT (' IYEAR=',I2,' IMONTH=',I2,' DAY=',I2,' JULIAN DAY=',      MET03120
01172         *F5.0,' SUNRISE=',F7.3,'  SUNSET=',F7.3)                                      MET03130
01173   560   FORMAT (' KST= ',24(I1,4X))                                                   MET03140
01174   570   FORMAT (' SPEED=  ',24(F4.1,1X)/' TEMP=',24(F4.0,1X)/' AFV= ',24(FMET03150
01174         14.0,1X)/' FVR=',24(F4.0,1X)/' HLH1=',12(F5.0,1X)/6X,12(F5.0,1X)/' MET03160
01174         2HLH2=',12(F5.0,1X)/6X,12(F5.0,1X))                                           MET03170
01175   580   FORMAT (' ALL RECORDS HAVE BEEN PROCESSED')                                   MET03180
01175         C                                                                             MET03190
01176         END                                                                           MET03200
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REFERENCES - APPENDIX E

Turner, B. D., "Relationships between 24-hour Mean Air Quality Measurements and Meteorological Factors in Nashville, TN." J. Air Poll. Control Assoc., 11: 483 (1961).

APPENDIX F

PLANT SPECIES ASSOCIATED WITH
COMMUNITY TYPES IN THE
PRUDHOE BAY AREA

WET MEADOW COMMUNITY

Grasses:

Alopecurus alpinus

Dupontia fischeri psilosantha

Hierochloe pauciflora

Sedges:

Carex bicolor

- *aquatilis*
- *capillaris*
- *chordorrhiza*
- *lachenalii*
- *lugens*
- *membranacea*
- *microglochin*
- *misandra*
- *physocarpa*
- *rariflora*
- *rotundata*
- *williamsii*

Cottongrasses:

Eriophorum angustifolium

- *callitrix*
- *russeolum leucothrix*
- *scheuchzeri*

Horsetail:

Equisetum palustre

Rushes:

Juncus biglumis

- *triglumis*

Rushes (continued):

- *Scirpus caespitosus austriacus*

Small heath shrubs:

- *Andromeda polifolia*
- *Chamaedaphne calyculata*
- *Ledum palustre decumbens*
- *Oxycoccus microcarpus*

Small willows:

- *Salix fuscescens*
  - \- *pulchra*
  - \- *reticulata*
  - \- *richardsonii*

Herbs:

- *Cardamine pratensis*
- *Chrysosplenium tetrandrum*
- *Lysiella obtusata*
- *Pedicularis pennellii*
  - \- *sudetica*
- *Petasites frigidus*
- *Pinguicula villosa*
  - \- *vulgaris*
- *Rubus chamaemorus*
- *Saxifraga cernua*
  - \- *foliolosa*
  - \- *hirculus*
- *Tofieldia pusilla*
- *Triglochin maritima*
- *Valeriana capitata*

AQUATIC LAKE COMMUNITY

Submerged rooted aquatics:

- *Potamogeton* spp.
- *Ranunculus gmelini yukonensis*
- *Sparganium hyperboreum*

Emergent rooted aquatics:

- *Arctophila fulva*
- *Equisetum limosum*
- *Hippuris vulgaris*
- *Menyanthes trifoliata*
- *Potentilla palustris*
- *Ranunculus pallasii*

Marginal emergent aquatics:

- *Carex aquatilis*
- *Eriophorum angustifolium*
- *Caltha palustris arctica*
- *Alopecurus alpinus*

COTTONGRASS MEADOW COMMUNITY

Grasses and sedges:

- Eriophorum vaginatum spissum
- Arctagrostis latifolia
- Carex bigelowii
- Festuca brachyphylla
- Juncus biglumis
- Luzula confusa
- Poa arctica

Small shrubs:

- Betula nana exilis
- Dryas integrifolia
- Empetrum nigrum
- Ledum palustre decumbens
- Salix pulchra
  - \- reticulata

Herbs:

- Eutrema edwardsii
- Polygonum bistorta plumosum
- Rubus chamaemorus
- Saussurea angustifolia
- Saxifraga hieracifolia
  - \- punctata nelsoniana
- Chrysosplenium wrightii

FLOODPLAIN AND BANK COMMUNITIES

EARLY SUCCESSIONAL

Horsetails:

Equisetum arvense

- *variegatum*

Grasses:

Agropyron spp.

Arctagrostis latifolia

Bromus pumpellianus

Calamagrostis inexpansa

Deschampsia caespitosa

Festuca altaica

- *rubra*

Hierochloe alpina

- *odorata*

Poa arctica

- *glauca*

Trisetum spicatum

Sedges and rushes:

Carex aquatilis

- *membranacea*
- *physodcarpa*
- *rupestris*

Eriophorum angustifolium

- *scheuchzeri*

Juncus arcticus alaskanus

- *castaneus*

Luzula spp.

Herbs (continued):

Papaver macounii

Parnassia kotzebuei

Pedicularis spp.

Phlox sibirica

Polemonium spp.

Saxifraga spp.

Senecio lugens

Solidago multiradiata

Taraxacum spp.

Zygadenus elegans

LATE SUCCESSIONAL

Trees:

Populus tacamahacca

Salix alaxensis

Shrubs:

Alnus crispa

Salix arbusculoides

- *desertorum*
- *glauca acutifolia*
- *niphoclada*
- *pulchra*
- *richardsonii*
- *walpolei*

Shepherdia canadensis

Herbs:

Aconitum delphinifolium

Shrubs:

Potentilla fruticosa

Salix alaxensis

- arbusculoides
- niphoclada
- pulchra
- richardsonii
- walpolei

Shepherdia canadensis

Herbs:

Artemisia arctica

- tilesii

Aster sibiricus

Astragalus alpinus

- umbellatus

Cardamine richardsonii

Castilleja pallida

Cerastium beeringianum

Draba spp.

Epilobium angustifolium

- latifolium

Erigeron spp.

Erysimum pallasii

Hedysarum alpinum americanum

- mackenzii

Lupinus arcticus

Melandrium spp.

Merckia physodes

Minuartia spp.

Oxytropis spp.

Herbs (continued):

- <u>Anemone richardsonii</u>
- <u>Astragalus eucosmus</u>
- <u>Dodecatheon frigidum</u>
- <u>Hedysarum alpinum americanum</u>
- <u>Parnassia palustris</u>
- <u>Pedicularis capitata</u>
  - <u>verticillata</u>
- <u>Polemonium acutiflorum</u>
- <u>Polygonum viviparum</u>
- <u>Primula egaliksensis</u>
- <u>Pyrola grandiflora</u>
  - <u>secunda obtusata</u>
- <u>Valeriana capitata</u>